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VALUE SHIFTS: The rise of multifunctional infrastructure

Author
Schaffler, Alexs

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The rise of multifunctional infrastructure

By

Alexis Schäffler

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Committee in Charge:

Professor Kristina Hill

Professor Louise Mozingo

Professor John Radke

Professor Carolina Reid

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Abstract

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Professor Kristina Hill, Chair

This dissertation examines the influence of urban sustainability on urban infrastructure. Thinking and practice around urban sustainability advocate the integration of urban services, such as water supply and sanitation, with goals such as natural resource conservation, climate mitigation and adaptation. I reflect on these multifunctional ideas about infrastructure in terms of the contexts taking charge of urban sustainability as a concept as well as a practical design experiment.

Reflecting critically on the theory of urban sustainability, this dissertation shows how urban water infrastructure practices are critical in evolving conceptions about infrastructure. A history of urban water infrastructure specifically highlights the role of design experiments and evolving methods of practice revealed in urban sustainability ideas. The dissertation develops an ethnomethodology to examine the infrastructural methods behind urban infrastructure practice in Johannesburg, South Africa.

As in many other African contexts, in Johannesburg, the single biggest investment to sustain future development will be in urban water systems, given that future water services depend on increasingly fragile natural resources and a changing climate. Apartheid era legacies of inequality remain, manifesting in disparate access to essential services such as fresh water and sanitation. The familiar "service delivery" agenda of many African governments, intersects with rapid urbanization that overrides much of the infrastructure already in place, requiring even greater investments to meet new urban needs.

An ethnomethodology of infrastructure practice in Johannesburg informs my empirical assessment of responses to urban sustainability. I reveal the contexts that lie behind the scenes of the proverbial "end of the pipe" and that are essential in terms of the methods for activating urban sustainability. In light of the conceptual and practical trajectory of urban sustainability, this dissertation is part of a wider enquiry into how urban

sustainability emerges in Johannesburg, compared to the global North, and into the practices that are available in each area.

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Acronyms and abbreviations

AM	Asset Management
AMD	Acid Mine Drainage
AMSCE	American Society for Civil Engineers
APA	American Planning Association
BCA	Benefit Cost Analysis
BEPP	Built Environment Performance Plan
BES	Bureau of Environmental Services
BRT	Bus Rapid Transit
CAPS	Capital Planning System
CIF	Capital Investment Framework
CIMS	Capital Investment Management System
CIP	Consolidated Infrastructure Plan
CIPA	Capital Investment Priority Areas
CoF	Corridors of Freedom
CoJ	City of Johannesburg
CSO	Combined Sewer Outflows
CSO	Combined Sewer Overflows
CWA	Clean Water Act
DBSA	Development Bank of South Africa
DORA	Division of Revenue Act
DPD	Development Planning Department
DPW	Department of Public Works
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
EIA	Environmental Impact Assessment
EISD	Environment and Infrastructure Services Department
ESA	Endangered Species Act
GCR	Gauteng City-Region
GCRO	Gauteng City-Region Observatory
GDS	Growth and Development Strategy
GI	Green Infrastructure
GIS	Geographic Information Systems
GJTMC	Greater Johannesburg Transitional Metropolitan Council
GMS	Growth Management Strategy
GPRA	Government Performance and Results Act
GSI	Green Stormwater Infrastructure
GSSP	Green Strategic Programme for Gauteng
IAM/S	Infrastructure Asset Management/Systems
IAMP	Infrastructure Asset Management Plans
IDP	Integrated Development Plan
IPCC	Intergovernmental Panel on Climate Change
IUPP	International Urban Planning and Policy
IUWM	Integrated Urban Water Management
IVRS	Integrated Vaal River System

IWRM	Integrated Water Resource Management
JRA	Johannesburg Roads Agency
JSIP	Johannesburg Strategic Infrastructure Platform
JW	Johannesburg Water
LAF	Landscape Architecture Foundation
LCA	Life Cycle Analysis
LHWP	Lesotho Highlands Water Project
LID	Low Impact Development
LoS	Level of Service
MCA	Multi-Criteria Decision Analysis
MCDA	Multi-Criteria Decision-Making
MEA	Millennium Ecosystem Assessment
MFI	Multifunctional Infrastructure
MFMA	Municipal Financial Management Act
MLC	Metropolitan Local Council
MOE	Municipal Owned Entity
MS4	Municipal Separate Storm Sewer System
MSCOA	Municipal Systems of Chartered Accounts
MTEF	Medium Term Expenditure Framework
MTLC	Midrand Transitional Local Council
NDS	Natural Drainage Strategy
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
NPM	New Public Management
PPE	Property, Plant and Equipment
RLDP	Rapid Land Development Programme
RSA	Republic of South Africa
SDF	Spatial Development Framework
SDG	Sustainable Development Goal
SEA	Street Edge Alternatives
SEM	Socio-Economic Model
SFPUC	San Francisco Public Utilities Commission
SGA	Sub-Global Assessment
SHSUP	Sustainable Human Settlements Urbanization Plan
SOC	State Owned Companies
SPU	Seattle Public Utilities
SSIP	Sewer System Improvement Program
STA	Spatially Targeted Areas
SUD	Sustainable Urban Development
SUWM	Sustainable Urban Water Management
TOD	Transit Oriented Development
TVAS	Thukela–Vaal Augmentation Scheme
UAF	Unaccounted-For Water
UG	Urban Geography
UGB	Urban Growth Boundaries
ULAEP	Urban Landscape Architecture and Environmental Planning

UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UoW	University of Washington
UPE	Urban Political Ecology
URS	User Requirement Specification
US	United States
USACE	United States Army Corps of Engineers
WCC	World Water Council
WDM	Water Demand Management
WHO	World Health Organization
WPCAA	Water Pollution Control Act Amendments
WRC	Water Research Commission
WSUD	Water-Sensitive Urban Design

Chapter 1: Introduction

1.1 A personal reflection

The prompt for this dissertation is a growing demand for urban sustainability that calls for change in the conception of urban infrastructure and the way it develops in practice. My academic and professional life connects me to urban infrastructure thinking in both South Africa, my home country, and the United States, where I have responded to this call by pursuing a doctorate in Landscape Architecture and Environmental Planning at the University of California, Berkeley.

This study is in part a personal reflection on my academic and professional experience in the field of urban sustainability. Having lived in Johannesburg and worked professionally on the search for more sustainable futures for the city, I have become aware of a conundrum complicating this vision. My work as an academic and policy advisor in Johannesburg revealed that despite clear political interest in urban sustainability, government is engaged in a deeply unsustainable urban project of long-standing on which the residents of the broader region, the province of Gauteng, rely (Götz & Schäffler, 2015: 82). This dissertation addresses this confrontation and reflects on how urban sustainability necessitates value shifts in society. My experience as a policy advisor and researcher at the Gauteng City-Region Observatory (GCRO)[1] raised the question of what sustainability means in practice, and how normative proposals for urban sustainability materialize.

This dissertation examines the extent to which urban sustainability requires a value shift in both the theory and the practices relating to infrastructure, and makes four primary contributions. The first contribution is a review of urban sustainability as an idea and how it manifests in practice, highlighting the overlapping roles of concept, theory and practice in articulating multifunctional ideas about infrastructure.

The second contribution is the development of a cultural approach to studying

[1] The GCRO is a partnership between the University of Johannesburg (UJ), the University of the Witwatersrand, Johannesburg (Wits) and the Gauteng Provincial Government (GPG). It is charged with providing improved data, information, research, analysis and reflective evaluation essential to better planning, management and co-operation between government, civil society and business in this fast growing and dynamic urban region.

infrastructure, using infrastructure practice as knowledge about values. Specifically, this dissertation represents the methods and tools of infrastructure practice as new knowledge about how urban sustainability manifests.

A cultural approach to infrastructure offers two related contributions to existing studies of Johannesburg. Using a series of anecdotes, the dissertation intervenes in existing scholarship by reconsidering Johannesburg's infrastructure challenges from the municipality's perspective. The case study on Johannesburg also updates existing research by tracing the decision tools that underlie a series of unfolding planning processes relating to infrastructure support in the municipality.

1.2 Research questions

The purpose of this study is to examine urban sustainability as a value shift, specifically in terms of urban water infrastructure. The three questions that guide this research are:

1. To the extent that there is a value shift towards urban sustainability, what are its ideological, conceptual and practical engagements?
2. What does the history of urban water infrastructure planning, development and use reveal about the evolution of the concept of urban sustainability towards multifunctional ideas?
3. What methods can be used to evaluate multifunctional infrastructure?

1.3 Research methods

The research methods used in this study included review and analysis of relevant literature in the field of urban infrastructure and sustainability, as well as observation and semi-structured interviews. These engagements included scholars concerned with the theory of urban sustainability and participants involved in the practice of urban infrastructure planning as well as development.

1.3.1 Literature review and analysis

Understanding the trajectories of concepts over time and assessing evidence of changes in discourse requires a review of both archival and current literature. Two categories of literature, academic planning scholarship and practitioner texts, are important evidence of the definitions used and the design and management practices foregrounded in urban water infrastructure discourse.

Academic scholarship is a cultural artifact in which academia presents ideas, propositions and commentary about reality (Badley, 2004). Studying the use of academic discourse in the political sphere draws on Hajer's reflexive approach to the research–advocacy relationship (Hajer, 1993: 44). This dissertation draws on academic planning scholarship to determine how theoretical conceptions and advocacy for urban sustainability affect urban water infrastructure in practice.

Important strategic and procedural texts such as government reports, planning documents and legislation records in practitioner archives are central to the examination of infrastructure planning and the determination of how urban sustainability manifests. Important decision-making tools that practitioners use in their work including Geographic Information Systems (GIS) and capital investment prioritization tools are also considered. The growing interest in Infrastructure Asset Management (IAM) as a capital investment and infrastructure decision tool warrants particular attention.

1.3.2 Participant observation

Building on Haas' conceptualization of epistemic communities as "a network of professionals with recognized expertise and competence in a particular domain and an authoritative claim to policy-relevant knowledge within that domain or issue-area" (Haas, 1992: 3), this research observes a variety of actors in the nexus between urban infrastructure and urban sustainability.

While some institutional practitioners, such as municipal planners or engineers, play important roles in infrastructure development practice, there are less obvious but equally significant actors in the evolution of infrastructure concepts, such as private consultants and scholars. Participants under observation therefore include not only government employees, but also non-governmental advisors, planners and policy-makers active in the practice of urban infrastructure planning and development, as well as academics concerned with the theory of urban sustainability. I refer to these scholars as "academic planners" or "academic activists".

The research focuses on current and previous employees of the City of Johannesburg (CoJ) to obtain the governmental perspective. The study also observes the work of private companies and consultants where planning, financing, operating, or maintaining infrastructure is outsourced (Eales, 2008: 5; Palmer et al, 2015: 7-13).

Swilling and Hajer's work on the research–advocacy nexus details how academic researchers not only formulate joint policies on sustainability and infrastructure, but also occupy positions of critical reflexivity between advocacy and discursive research (Swilling, 2014: 1; Hajer, 1995). Academic planners with expertise in urban infrastructure planning and sustainability therefore play an important dual role in critical thinking and policy advisory. In South Africa, academic researchers played an important part in the history of anti-apartheid activism, using sustainability as an argument for contemporary theoretical and political change (Swilling, 2017; Pieterse, 2017). There are similar global examples of academic planners using consulting positons as forms of academic advocacy (Munton et al, 2003: 135; Swilling, 2014; Allen et al, 2016).

This research therefore observes how these epistemic communities, in line with Haas' conceptualization, engage in urban sustainability and infrastructure practice. Research meetings with the Gauteng City-Region Observatory (GCRO) provide the opportunity for observing urban sustainability narratives in relation to themes of urban infrastructure. In these key research discussions, I occupy the role of observer and explain to the participants my research tracing the contexts of sustainability over time.

My previous occupation as an academic planner means that much of the research in this study also draws on my own historical experience and observation.

1.3.3 Semi-structured interviews

Semi-structured interviews are verbal interchanges where the interviewer attempts to elicit information in a conversational manner (Longhurst, 2016: 143). The researcher explains to interviewees that they should only offer information they are comfortable about disclosing, and if participants express ethical opinions, the data is presented anonymously (Longhurst in Clifford et al, 2016: 152; Cameron in Hay, 2004: 155). In this study, semi-structured interviews form part of researching the capacity of infrastructure planning systems to respond to urban sustainability in the City of Johannesburg (CoJ) as a case study.

To clarify the facts of infrastructure management in the CoJ, the case study investigates the history of municipal amalgamation of the CoJ, and this gives rise to a series of new infrastructure planning tools. While public information about the municipal amalgamation is available in municipal documents, semi-structured interviews assist in clarifying the history and functions of the emergent planning tools.

1.4 Dissertation overview

The dissertation is structured in three parts: Part 1 (Chapters 2, 3 and 4) deals with urban sustainability, infrastructure and water, Part 2 (Chapters 5 and 6) addresses infrastructure practice as new knowledge, and Part 3 (Chapter 7) presents the conclusions that can be drawn from this research.

In Part 1, Chapter 2, *Urban Sustainability*, explores the policy, as well as the scholarly and practical purchase of urban sustainability as a social value. The chapter considers diverse active urban sustainability agendas and the common ground emerging in relation to urban infrastructure. The chapter highlights the policy–science nexus driving urban sustainability, and the role of applied practices and experiments, in particular. An urban services heuristic is put forward as a framework for evaluating urban sustainability.

Chapter 3, *Urban Infrastructure*, reflects on the functions, design and management of urban infrastructure since the industrial revolution. The chapter follows the historical trajectory of eras and movements since the industrial revolution that give rise to various ideas about urban water. These contexts are important triggers for sustainability initiatives in the latter part of the twentieth century. A key focus is on the role of pilot projects and the methods of infrastructure practitioners to demonstrate sustainability in practice.

In Part 2, Chapter 4, *Infrastructure as a Cultural Topic*, uses ethnomethodology to expand on current cultural approaches to studying infrastructure. The chapter calls for moving beyond institutional readings of infrastructure by using methods of practice as knowledge about sustainability and infrastructure functions.

Chapter 5, *Johannesburg*, revisits the infrastructure challenges facing Johannesburg, from the perspective of the municipality. Using water as a focal point, the chapter shows that the municipality faces some conundrums in competing demands considers, but that there is also an important municipal history of understanding infrastructure. Recent momentum surrounding sustainability and green infrastructure shows the potential for transformation that rests in municipal planning narrative, technical experiments and institutional memory.

Finally, in Part 3, Chapter 6, *Concluding thoughts and research implications* summarizes the key findings and contributions of this research. The chapter also looks ahead to outline the areas of further research that could build on the insights presented in this dissertation.

PART 1: URBAN SUSTAINABILITY, INFRASTRUCTURE AND WATER

Chapter 2: Urban sustainability

2.1 Introduction

Urban sustainability is a common agenda in global policy and promoting sustainability as a strategic value for cities appears to be a key motivation for multilateral agencies. The general concept of sustainability makes sense as cities encounter various environmental pressures including climate change, resource uncertainties, concerns about the future of infrastructure and services, economic challenges and various ongoing social struggles.

Although the general concept of urban sustainability is critical to the future of cities, scholars and practitioners from different disciplines frame the concept of urban sustainability using a diversity of theories, principles and criteria. In all its diversity, urban sustainability has currency in policy agendas as a theory as well as a practice around which, increasingly, various disciplines coalesce. This chapter takes as its premise a perceived value shift in society towards urban sustainability and examines the communities taking charge of its evolution as well as the nature of this engagement.

The chapter conducts its enquiry at two intersecting levels. The first level of analysis relates to the rise of urban sustainability as a policy mandate and subset of the broader sustainable development agenda. The second level of analysis examines the key scholarly and practicing communities positioning themselves in urban sustainability as an epistemic project, drawing on Haas's idea of how policy projects emerge through shared values and discursive practice (1992: 4). The chapter focuses on International Urban Planning and Policy (IUPP), Urban Geography (UG) and Urban Landscape Architecture and Environmental Planning (ULAEP), as key communities engaging in urban sustainability policy theory as well as practice.

In reflecting on how scholars and practitioners engage with urban sustainability, the chapter connects several literatures to show the disciplinary roots of high-level concepts and policy agendas. While this contribution rests on highlighting the diversity of engagements with urban sustainability, the chapter also shows a common theme emerging around urban infrastructure as a strategic mechanism and, specifically, as a source of practical experimentation in how cities function. Finally, in setting out this common ground, the chapter proposes urban services as a framework for evaluating urban sustainability as a concept, as well as a practice of infrastructure. This insight forms the basis for Chapter 3, which examines urban infrastructure over time and the role of sustainability experiments in overturning ideas about the functions of infrastructure.

2.2 The rise of a policy value

During the 1980s, sustainable development gained in popularity as a policy mandate in multilateral institutions and faced few challenges. There are desirable ethical stances in aligning with sustainable development, for instance, the Brundtland Commission follows an attractive agenda – to balance environmental health, economic prosperity, and social equity goals, and "meet the needs of the present without compromising the ability of future generations to meet their own needs" (UN, 1987: 43).

Brundtland's use of the term "sustainable" can be interpreted as investment in the long-term future of the human race and it encompasses the principle of intergenerational equity (Jepson, 2001: 503). There are several layers of ambiguity inherent in the Brundtland concept of intergenerational equity that continue to fuel a lively dialogue of scholarly reflection and debate (Bartlett, 2006: 19-22; Jepson, 2001: 503, Meadowcraft, 2011). A general breach exists between American and European discourses concerned with retrofitting existing consumptions and development, and a Global South discourse where new investment, equity and access are urgent priorities (Lee, 2006: 9-10; Swilling, 2006).

In light of the North–South disjuncture, a popular debate relates to what exactly to sustain, and for whom (Lee, 2006: 9; Swilling, 2006; Childers et al, 2014: 321; Sánchez-Rodríguez, 2008). The German term "nachhaltigkeit", meaning self-restraint as well as sustainability, is indicative of some of the underlying linguistic complexities that may affect social interpretations (Keirstead & Leach, 2008: 330). However, the main rallying points relate to the ability of other generations and communities, both human and non-human, to meet their respective needs in the future (Lee, 2006: 9-10; Keirstead et al, 2008: 330; Marcuse, 2006: 60).

Morin calls the numerous contemporary challenges that affect current development the "polycrisis" (1999: 73). The appearance of sustainable development agendas in the 1980s reflects a multilateral response to these challenges and how they will affect future generations. As a policy mandate, urban sustainability is suggestive of what Oels terms "collective action problems" (2005: 196), that is, constructions of morality in which there are often paradoxes and conundrums challenging action.

A major issue like the 1972 oil crisis raises social awareness about resource shortages limiting economic growth (Meadows et al, 1972: 67; Hawken et al, 1999). Publications such as *Limits to Growth* (Meadows et al, 1972) and the idea of "natural capital" (Hawken et al, 1999) also play formative roles in the discourse around natural resource shortages. Following an energy crisis, ideas about resource efficiency, productivity and regeneration gain traction, together with a host of applied tools to measure resource flows through infrastructure (Hawken et al, 1999: 11; Daly, 1990: 3). Wolman's urban metabolism concept is an early example of the interest in resource efficiency and the modelling of resource inputs and outputs at a city scale (Wolman, 1965: 156). Many more recent industrial ecology tools, such as Life Cycle Analysis (LCA) and Metabolic Flow Analysis (MFA), have roots in the resource efficiency principles of the late twentieth century (Kennedy et al, 2010: 1; Hodson et al 2012: 790; Decker et al, 2000: 685; Barles, 2009: 898).

As Chapter 3 shows, there is an influential history of environmental regulation that precedes sustainable development, and which largely overtakes "environmentalism" as a social movement (Marcuse, 2006: 56). For instance, the passing of environmental legislation during the 1960s and 1970s in a number of developed countries leads to the institutional adoption of the concept of Environmental Impact Assessment (EIA), which allows governments and the private sector to "green" their activities by reducing negative environmental impacts or externalities (Keen et al, 2005: 5; Berkhout et al, 2003: 4). In the US, the 1969 enactment of the National Environmental Policy Act (NEPA) demonstrates how environmental protection concerns manifest institutionally through underlying narratives about "wilderness" and "unspoiled natural beauty" (Keen et al, 2005: 5).

In many ways, the environmental protection ethic reflects the "restoration project" (Katz, 2000: 86) and is emblematic of a social optimism about technological solutions for repairing natural environmental degradation. There are etymological indications that moral acceptance and the desire for change for "the greater good" underlie the popularity of the sustainable development agenda (Katz, 2000: 85; Marcuse, 2006: 56). The word "sustainable" in *sustainable* development, for instance, reveals social optimism about a current trajectory and the potential for change, that is, to make a "better environment" (Beatley, 1995: 339). Several technical innovations in cities termed "eco-" or "smart-" also reflect optimism about the possibilities of creating apparently environmentally "greener" designs (Marcuse, 2006: 60; Simon, 2016: 79).

Recently, "sustainable development" and "sustainability" have become interchangeable in the policy lexicon, spearheading a host of interpretations and ambiguities, and several conceptual deadlocks (Bartlett, 2006: 1). Debate in the policy discourse around Brundtland's principles continues, and the call for a change in values towards an environmental ethic is ongoing. Daly's "limits to growth" argument comes under particular scrutiny for overlooking the major structural economic inequities that underpin unsustainable development (Daly, 1990: 2; Swilling et al, 2010). Critical scholars point to how sustainability largely develops as a policy mandate, in North American and European contexts, involving sustaining current development while disregarding the continuation of major social injustices (Marcuse, 2006: 57). Political ecologists also challenge the momentum of environmental decision-making as a product of capital and power relations that restructure policy to retain control (Swyngedouw & Heynen, 2003). The Global Environment Facility (GEF), a trust that developed from the 1992 Rio de Janeiro Earth Summit, offers such critique. Using contributions from donor countries, the GEF supports projects in developing countries that meet the objectivities of international environmental conventions (GEF, 2018).

Notions of "just sustainability" or "just transition" emerge in sustainability agendas for the explicit inclusion, if not prioritization, of the Global South (Agyeman & Evan, 2004: 155; Lee, 2006: 9; Swilling, 2006; Childers et al, 2014: 321). In the twenty-first century, the policy shift discourse partly corresponds to urbanization patterns in development, from which the key global development communities gain a cause and a validation. At the same time, there is also a general reorientation of sustainability agendas across the world from a national to a city scale, that calls for an enquiry into the supporting underlying discursive processes.

The following section examines the focus on cities in sustainability agendas, and the associated engagement of key scholars and practitioners.

2.3 Cities and sustainability

After the 1992 Conference on Environment and Development in Rio de Janeiro, and the implementation of the Habitat Agenda 21, cities become the focus in United Nations policy, which emphasizes improving human settlements and foregrounds the role of local government in achieving sustainability (Bulkeley, 2006: 1036). Terms such as "sustainable urbanization" and "sustainable cities" become common in UN communications with the rallying cry that the "global sustainability battle will be lost or won in cities" (UNFPA, 2015; UN-Habitat, 2012; Mukherjee, 2015: 133).

Urban sustainability gains further traction in 2016 at the UN Conference on Housing and Sustainable Urban Development in Quito. *Habitat III,* the "New Urban Agenda"*,* a blueprint for sustainable and livable cities, is launched at the conference, and it calls for national governments and international financial institutions to help finance low carbon and sustainable projects (UN-Habitat, 2017). The focus is also on cities in SDG 11, *Sustainable Cities and Communities,* which emphasizes adequate, safe and affordable basic services and infrastructure (UN-Habitat, 2017).

While the UN is a major driver of global sustainability policy, several transnational networks of cities also emerge, providing advice, practical support and leadership opportunities (Palmer & Simon, 2016: 160). ICLEI, Local Governments for Sustainability, which already exists as a concept in 1989, becomes a network of more than 1 500 cities, towns and regions working in collaboration to respond to global environmental problems (ICLEI, 2018). Other initiatives, which despite only obliquely aligning to environmental agendas such as "climate change" or "resilience", also reflect the significant rise of transnational urban sustainability networks. The Rockefeller Foundation's 100 Resilient Cities Initiative and the C40 Cities Climate Leadership Group are prominent examples of networks focusing on linking cities transnationally for sustainability policy development, learning and advocacy (Zeemering, 2014: 122).

The rise of transnational networks is indicative of a trend towards cities using sustainability as an opportunity for redefining their strategic and leadership visions. For example, in the US, the mayors of Los Angeles and New York work towards making their cities the "greenest in the world" by investing in large-scale tree planting projects (Pincetl, 2010: 43-44). Portland, which stands out as an early sustainability prototype, uses sustainability as an overarching city vision and to drive specific projects, such as the reinvigoration of the inner city through infrastructure retrofits, and the pilot of the famous Transit Oriented Development (TOD). Portland's history of natural drainage experiments highlights infrastructure design as a key component of sustainability visions for cities (Fishman, 2011: 38; Senville, 2014). There is similar evidence from the UK, where urban regeneration in the post-industrial cities of Manchester and Leeds is supported by "eco-investment" and environmental restoration (While et al, 2004: 550).

In policy discourse, a city's investment in alternative infrastructure approaches also provides a valuable evidence base for the strategic shift towards sustainability. The 2012 UN-Habitat series, *Urban Patterns for a Green Economy: Optimizing Infrastructure*, argues for reconsidering the connections between city users and natural resources, and profiles alternative infrastructure systems such as Bus Rapid Transit (BRT) and waterless sanitation as ways for cities to leverage infrastructure investments as catalysts for sustainability (UN, 2012: ix). While no means mainstream, these systems demonstrate how sustainability manifests in different conceptualizations and designs of infrastructure. This rethinking reveals how infrastructure investments for sustainability can be fundamental components of the provision of infrastructure services.

Notwithstanding the important role of infrastructure as a mechanism for sustainability, many cities also use sustainability as an opportunity for addressing more prosaic urban management issues, such as retrofitting aging infrastructure and the provision of urban services in general. Broto & Bulkeley's (2013: 362) survey concludes that urban sustainability experiments are often responses to the need for the "development, repair and maintenance of the city". Paradoxically, therefore, in the context of resource constraints and environmental pressures, which certainly exacerbate some basic urban issues, the arrival of urban sustainability thinking is opportune for cities needing to rethink their visions and everyday management. Infrastructure investments can be forms of environmental "security", offering cities protection from climate change and resource constraints (Hodson & Marvin, 2009: 254).

The position of urban infrastructure in sustainability discourse therefore suggests this is a critical juncture for the historically ambiguous and challenging framework. To explore this observation in more detail, it is important to understand the disciplinary roots of urban sustainability in terms of the key scholarship and practice behind its evolution.

2.4 Disciplinary engagements with urban sustainability

2.4.1 International Urban Policy and Planning (IUPP)

In light of current demographic trends, Towards the 21st century, the developing world becomes is increasingly ostensibly more relevant to policy institutions in the twenty-first century in light of major demographic trends. In contrast to a first major wave of urbanization in Europe during the industrial revolution, the late 20th century sees rapid urban growth is now occurring mainly in the developing countries of Africa, Asia and Latin America (UNEP, 2006, Pieterse, 2008). Evidence shows that, rather than in megacities, this second wave of urbanization is increasingly occurring in smaller urban regions, often those without the resources to cope with the pace of demand for infrastructure and services (Davis, 2005).

The second wave of urbanization is visualized through the countless images issued by multilateral organizations that contrast burgeoning African slum settlements having acute deficits in access to basic services, such as Lagos in Nigeria, with the "greenest cities of the world" such as Vauban eco-city in Freiberg, Germany, which has large-scale solar settlements (UNEP, 2013: 65; UN-Habitat, 2010). The emphasis in these binary perspectives is often on the differential nature of urbanization in the Global North and the Global South:

> [C]ities of the global 'north' are straining under creaking infrastructures, requiring replacement and ideally, a shift to greater resource efficiency, while cities in the global 'south' face severe infrastructural deficits and backlogs, and acute lack of access to essential services (Pieterse & Hyman, 2014: 191).

There is a common "storyline" (Hajer, 1993: 47) about urban infrastructure in IUPP communities. The urban infrastructure narrative is a union between two general disciplines: sustainability transitions literature and critical urban theory. While several actors influence sustainability initiatives, the UNEP chapter is the key multilateral initiative evolving urban sustainability through specific theories relating to decoupling, infrastructure transitions and critical urbanism. In *City-Level Decoupling: Urban resource flows and the governance of infrastructure transitions,* a joint publication by the United Nations Environment Program (UNEP) and the International Panel (IRP), the key argument is that, to shift to a different resource path, urban sustainability needs to "design, fund and build" the "kind of infrastructure ... to ensure our cities become more sustainable in the future" (UNEP, 2013: 15). The UNEP/IRP report hinges on the principle of decoupling, or reducing the amount of resources such as water and fossil fuels used, while producing economic growth and development that is not linked to environmental deterioration (UNEP, 2013: xi). There are two types of decoupling: more narrowly, decreasing negative environmental impacts, and more broadly, decoupling economic activity from resource consumption (Hodson et al, 2012: 798).

The *City-Level Decoupling* argument is part of a wider discourse that:

> [i]nfrastructure transitions are necessary for sustainable urban futures wherein decoupling is used as a theoretical framework for development and infrastructure is the intervention point (Hyman, 2013: 341).

The communities taking charge of the decoupling narrative emphasize infrastructure as a key analytical and strategic element relating resource use to developmental strategies (UNEP, 2013; Hodson et al, 2012). Infrastructure is emphasized because it is typically the largest expenditure item for city governments, and academics reference global trends evident in a 2011 report, *Lights!Water!Motion!,* by consulting firm Booz Allen Hamilton, which considers urban infrastructure as possibly the largest single investment for sustaining urban areas in the future (Doshi et al, 2011, also see Swilling, 2011: 80).

There are underlying influences on decoupling, from industrial ecology and principles of resource productivity and efficiency (Kemp & Van Lente, 2011). Industrial ecologists play a role in advancing sustainability science by examining resources flows through infrastructure, using tools such as Life-Cycle and Material-Flow Analysis (Guy & Marvin, 2001; Krausmann et al, 2008, Niza et al, 2009). Scholars studying "sustainability transitions" use these industrial ecology tools to develop theories about the evolution of urban sustainability in terms of transition (Murphy, 2015: 73-74; Markard et al, 2012: 961). The sustainability transitions concept has roots in transitions management, the multi-level perspective and technological innovation studies that concern how technological innovation systems affect broader "socio-technical" changes in different contexts, over time (Murphy, 2015: 75; Geels & Kemp, 2007: 442-44). The "transitions" notion is a useful heuristic in understanding and communicating urban sustainability as a structural form of change (Hodson & Marvin, 2009a; Krausmann et al., 2008; Smith et al., 2005).

A cohort of academic-planning activists, from critical perspectives such as political ecology and development state theory, are joining the discussion on decoupling and infrastructure transitions, especially at the urban scale (Hodson et al, 2010b; 2009a; Heynen, 2006, Swilling, 2011; Swilling et al, 2016). In South Africa, for example, academics employ urban sustainability as a vehicle for appealing to over-consuming urban areas to decrease consumption patterns (Swilling, 2006: 45, 2014: 1; Hyman, 2013: 84). South Africa also has a strong tradition of critical Marxism that has its roots in the anti-apartheid struggle, contributing to sustainability debates insights about the divisive impacts of neoliberal economic models that determine resource use, as well as the practical conundrums of shifting out of dominant development pathways (Swilling, 2014: 3180-3181; Burns & Weaver, 2008).

The tradition of critical theory is significant in terms of how academic planners, such as Mark Swilling, influence global policy agendas through their role as key contributors to UNEP and other global policy platforms. Swilling is one of the key contributors to the just transition discourse, advocating the use of "sustainability as a vehicle for changing theory and practice" (2008). Swilling is active on several global policy platforms, including UNEP-IRP and the UNEP Green Economy initiative, and thereby participates in theoretical collaborations in the discipline of sustainability science. The influence of critical scholars from political-economic backgrounds is represented in UNEP's Green Economy program, which frames itself as "a high-level policy dialogue … [in] the future of work in the transition to inclusive green economies … and the need to ensure a just transition for enterprises, workers and communities (UNEP, 2018). The notion of a "just transition" is described as:

> [a] transition to sustainable forms of development that leaves these socio-economic inequalities intact will not, in our view, deliver an end result that can be called sustainable. A just transition, therefore, must be a transition that reconciles sustainable use of natural

> resources with a pervasive commitment to what is increasingly being referred to as sufficiency (that is, where over-consumers are satisfied with less so that under-consumers can secure enough, without aspiring for more than their fair share) (Swilling & Annecke 2012: xiii).

Partnerships between Swilling and several leading industrial ecologists also address the modelling and analysis of resource flows (Hodson et al, 2012; UNEP, 2013). These academic partnerships contribute to scientific and policy arguments for decoupling through urban infrastructure transitions of:

> the vast networked urban infrastructures that connect everyday living and working, to the natural and informational resources, that urban dwellers depend on in a wide variety of ways across cities in the developed and developing world. The core argument is that investments in urban infrastructures may well become the focus of strategies to 'resolve' the global economic crisis, but in so doing key questions are raised about what kind of infrastructures will be designed, funded and built in order to make sure that cities become more sustainable in future (Swilling, 2011: 78).

In addition to the scientific modelling work that underpins decoupling theory, Swilling presents a key narrative about "sufficiency", which implies the poor "get more to have enough" while "the rich make do with less" (Swilling, 2011: 81-82; Revi et al, 2006: 62, Von Weizsäcker et al, 2009). Sufficiency rests on a key political-economic foundation:

> For about a billion of the wealthier urban dwellers this will entail drastic consumption reduction (from between 15 tons for Europeans and 30 tons for North Americans per annum to 6 tons per annum) and for the billion who live in slums it will mean significant increases in resource consumption (Swilling, 2011: 81-82).

A specific example is Swilling's "silver spoons" metaphor that refers to the highest income groups in Cape Town. These groups comprise only 7% of total households in the city area yet they use almost 60 % of all domestic water. An ongoing water supply crisis has resulted in a significant fraction of Capetonian households having no piped water supply at the time of writing (Swilling, 2006: 35).

The sufficiency narrative is important in terms of how UNEP policy reflects ideological positions and the conceptual roots of underlying epistemic communities:

> [C]ities are not the problem per se, rather, it is the nature of certain consumption and production patterns, as well as the rising levels of income and consumption levels that often accompany urbanization that raise urban sustainability concerns (UNEP, 2011: 458).

It is sometimes difficult to disentangle strategic visions from the influence of theory and power at the international urban policy and planning level (Hajer, 1990: 307). However, the rise of urban sustainability in IUPP shows how particular epistemic communities not only position themselves in multilateral platforms, but do so with specific disciplinary roots and intentions. These influences coalesce around urban infrastructure planning and implementation, not only as a critical narrative, but also as a practical mechanism for achieving theoretical or ideological ends.

2.4.2 Urban Geography (UG)

UG is an incredibly broad discipline, and although, for example, cultural and feminist geography have common roots in political-economic geography, they are sometimes viewed as independent intellectual developments (Lees, 2002: 102). Reflections that UG suffers from a lack of coherence in studying the "urban" from a geographical perspective are indicative of the discipline's intellectual disjunctures and diversity (Lees, 2002: 104; Thrift, 1993).[2]

There are also criticisms about the lack of scholarly attention to the geographic dimensions of urban sustainability from sustainability scientists (Coenen et al, 2012: 968-969; Braun, 2005: 635). Urban sustainability contributes to urban geography not purely as a technical or design matter, but also as an object for critical reflection (Braun, 2005: 640). Geographer Harriet Bulkeley's analyses epitomize the use of urban sustainability as a means for examining how policy goals manifest in different geographic regions (Bulkeley, 2006: 1035; Bulkeley & Betsill, 2005: 42-43, Broto & Bulkeley, 2013: 92). Bulkeley's interest is the divergence of urban sustainability movements in different cities around the world, reflecting the work of geographers who study space as a production of social factors (Lefebvre, 1991; Bulkeley, 2005: 48; Graham & Marvin, 1994: 628; Allmendinger, 2002: 5).

Urban geographers often employ concepts of "landscape" and "place" to assess the different scales at which urban sustainability manifests (Brandt & Vejre, 2004: 3). A common interest is the far-reaching landscape implications of changes to urban infrastructure and land use, particularly the effects of post-industrial sprawl and property-led investments in megaprojects (Brenner & Schmid, 2015). Critical scholarship also analyzes these trends in terms of underlying power and capital relations, for example, how the exposure of major urban infrastructure networks to the private sector results in "splintering" of services that often then bypass less lucrative areas (Graham & Marvin, 2001; 14-15).

[2] Lees reflects on Thrift's earlier provocation (see Thrift, 1993), that while there are important intellectual developments, there remain difficulties in the extent to which urban geography as a discipline coherently and productively studies "the urban".

Urban Political Ecology (UPE) contributes some very insightful empirical analysis by reflecting on the effects that political economic structures have on urban environments. UPE considers particular historical and geographical processes as well as the spatial dimensions of power relations (Heynen, 2006: 500). However, a possible limitation of radical theory is that it tends to pre-determine conclusions, such as assuming that government is adversely disposed to changes that do not favor privileged groups and dominant political and economic interests. There is a tendency to foreground the situation of cities in developing country to argue that issues such as urban informality and the politics of urban poverty are undermining urban sustainability progress (Parnell & Robinson, 2012: 595). This presupposes conditions about both the source of change and the values that manifest in urban sustainability planning or practice.

From positions in Cultural Geography (CG), there are various analytical attempts to explain urban sustainability as a product of cultural values that shape physical landscapes (Brandt & Vejre, 2004: 3, 28; Bergeron et al, 2014: 109; Antrop, 2006: 190). Cultural frameworks approach urban sustainability by way of an assessment of how human value systems re-define what is important in ecological terms (Potschin & Haines-Young, 2013). This perspective generally produces theories about urban sustainability as a manifestation or reflection of societal concern about the fate of the environment overlapping theories of place-making, cognition and landscape valuation studies (Bergeron et al, 2014: Meyer, 2008: 243; Elmqvist et al, 2015: 101).

The "Multi-Level Perspective" (MLP) conceptual framework is gaining traction in UG because it engages with urban sustainability. MLP aims to address sustainability at three analytical levels: niches, socio-technical regimes, and exogenous socio-technical levels (Geels, 2010: 495). A corresponding concept is "multi-level governance", which seeks to highlight the interaction between economic, social and political processes across different governance levels (Bulkeley & Betsill, 2005: 47). An example of how MLP can be applied to cities is the examination of how global climate action stimulates initiatives at the local planning level, yet specific interpretations and implementation are determined by other practitioners (Broto & Bulkeley, 2013: 93; Bulkeley, 2006: 1036).

MLP is part of a wider literature on sustainability transitions that expresses a particular interest in large-scale infrastructure changes that emerge from sustainability as a socio-technical transition (Geels, 2010: 496; Murphy, 2015: 74[3]). This branch of geography focuses not only on infrastructure regimes over time, but also on innovations across

[3] Murphy offers two contributions from urban geography. The first focuses on socio-spatial context and interaction and the ways these influence the aligning or anchoring processes that facilitate transition. The second draws on place-making theory to conceptualize the relational-political struggles and power dynamics of transition initiatives, highlighting the role that collective understandings play in shaping the prospects for achieving consensus regarding the evolution of socio-technical systems (Murphy, 2015: 76).

multiple sites and governance scales that affect why urban sustainability transitions do or do not occur (Bulkeley & Betsill, 2005: 47-48; Braun, 2005: 640; Gandy, 2004: 364; Guy et al, 2011).

While it is largely a theoretical discipline, UG offers important analytical lenses through which to observe the nature of sustainability in practice. This kind of ontology increasingly takes the practice of infrastructure and innovation in cities as evidence of sustainability that requires interpretation according to theoretical constructs (Geels, 2010: 499). The value of this empirical analysis is clear when considering experiments with urban sustainability in an applied community that specifically positions itself in the nexus between the physical environment and human activities.

2.4.3 Urban Landscape Architecture and Environmental Planning (ULAEP)

ULAEP is a discipline that is concerned generally with interactions between humans and the physical environment. While individual orientations are diverse, ULAEP scholars and practitioners express a common goal of integrating cultural and ecological perspectives (Johnson & Hill, 2002: 1). ULAEP practitioners are part of an applied community with the broader epistemic purpose of translating normative goals into action, particularly through design and physical planning guidelines in physical environments (Steiner et al, 2013: 356; Johnson & Hill, 2002: 7, 13).

In many ways, however, there is an ethical argument about "the environment" that is part of a wider reform of modernist planning (McHarg, 1969: 216; Spirn, 1984: 36; Jacobs, 1961; Carlson 1962). Jane Jacobs's foundational work critiques "orthodox" city-building planning as "pseudoscience", lamenting early movements such as Howard's *Garden Cities* (1902) for trading diverse urban forms for conformity and increased resource consumption (Jacobs, 1961, 1970). Such views regard the modernist planning project as the major culprit in the separation of urban areas from nature through physical alternations such as urban sprawl, as well as mental or psychological separations (McHarg, 1969: 216; Spirn, 1984: 31-36; Merchant, 1998: 69).

As is shown in more detail in Chapter 3, the ecological turn in urban planning is a major point of convergence in the attempt to integrate social and ecological values. The ecological turn connects to the evocative and powerful visions of "nature", and what Mozingo terms "conjectural hope", that appear frequently in ULAEP literature and design proposals (Mozingo, 1997: 46; Strang, 1996). Examples include Hough's ideological aspirations for "self-sustaining landscapes" (1989: 1; 1995: 183) and Spirn's career long search for a "new aesthetic" in design that integrates city and nature (1988:

108, 1997: 46). These proposals reflect a general desire for greater ecological literacy in planning, albeit with varying levels and types of engagement (Steiner et al, 2013: 356; Spirn, 1988: 108; Hough, 1989: 5, 1995: 183; Lyle, 1994: 3; Corner & Maclean, 2000; Thompson, 2012: 15).

An environmental ethic underlies many of the normative positions about "changing values" and biophysical limits as well as the ways we interact with, and modify, the natural environment (Hough, 1995: 1; Beatley & Manning, 1997; Merchant, 1998: 69). This ethic often considers cities that "adapt ingeniously to nature" to have an advantage in terms of deriving benefits from ecological goals in urban planning (Spirn, 1984: xi, 9-10). Reference is made to the history of "intuitive" environmental visions as evidence of a cultural shift away from the modernist project (Smith & Hellmund, 1993: xi; Meyer, 2008: 7; Spirn, 1984: 21, 32; Mozingo, 1997: 46; Czerniak, 2001). The oft-quoted embodiment of such concerns is the "monumental" joint project by Olmstead and Vaux in New York's Central Park, which was "carefully planned to mitigate the health and psychological effects of industrial life" (Fishman, 2011: 32-33; Kunstler, 2013: 30; Hill & Larssen, 2013). Scholars and practitioners also commonly celebrate Olmstead's design for the Boston Fens, and the Emerald Necklace more broadly, for combining drainage, transport, health, biodiversity and social goals (Spirn, 1984: 21, 32; Hill, 2009: 143-144). The subsequent filling of Boston's Back Bay and destruction of the brackish, tidal Fens estuary ecosystem has, however, increased the risk of flooding (Spirn, 1984: 21, 32; Meyer, 2008: 6).

Ethical standpoints relating to the environment enter contentious moral territory when environmental visions, wittingly or unwittingly, serve particular cultural contexts and exclude others (Hill, 1994: 146). Brown reflects on how ecological revelations create a moral "litmus" that deserves critical attention (1998: 54). In *The Ecological Imperative,* Walsh maintains that "the fundamental problem is not so much technology as it is psychology and the reordering of our priorities" (1993: 50). Nassauer emphasizes a need for "cultural sustainability" in terms of sustained human care for landscapes, that also requires a shift beyond common aesthetic norms (1997:b 69, 72-73). Merchant's "partnership ethic" is a similar call focusing on the need for both biological and cultural diversity in design (Merchant, 1998: 69).

While there are important cultural debates about the ethics of sustainability, the tradition of ULAEP also engages practically with the way cities function. Many of the iconic designs that work with "nature" are not only ideological causes, but also interventions in improving the ecological performance of a city (Hill & Larsen, 2013; Steiner et al, 2013: 355). In particular, there is a specific process of experimentation with design and planning guidelines to integrate ecological objectives in urban functions (Geddes, 1915;

McHarg, 1969; Spirn, 1984; Forman & Godron, 1986; Forman, 1995; France, 2002; Johnson & Hill, 2002; Hill, 2009; Hill & Larsen, 2013; Strang, 1996: 11; Steiner et al, 2013; Nijhuis & Jauslin, 2015: 14).

Chapter 3 reflects on the role of planning and design experiments as catalysts for urban sustainability in terms of a specific set of pilot projects in the late twentieth century that overturn preexisting ideas about infrastructure function. In the US, for instance, there are examples of landscape architects experimenting with natural drainage strategies. McHarg's significant experiment at *The Woodlands* embodies the catalytic role of a natural drainage system that utilizes existing floodplains, drainage channels, ponds and recharge soils, to achieve desired objectives (McHarg, 1973: 1). McHarg's project is a precedent that demonstrates the multiple benefits that experimental design and planning in the practice of sustainability can deliver (France, 2002: 1; Steiner et al, 2013: 355; Strang, 1996: 10). The history of working intuitively with nature celebrates the creativity as well as the shared responsibility of sustainable design and planning (Hill, 2009: 145; McHarg, 1973: 61).

Thompson provides the insight that while working through the nature–culture dichotomy is complex and challenging, design experimentation is an essential part of responsive, creative and catalytic thinking about the urban form and function (2012: 13-15). Fraker frames this as the environmental paradox of city-building processes, that is, the hangovers of history are also potential opportunities for sustainable urban form and design innovations (2013: 4). While these positions sometimes err on the conjectural, they also highlight the role of design and planning intervention in the practical engagement with urban sustainability. This engagement generally seeks greater synthesis between ecological and social values, not only ethically, but also in how cities function in providing services.

2.5 Conclusions and insights

Following the Brundtland agenda, urban sustainability gains momentum as a policy mandate in response to the second wave of urbanization, which places cities of the Global South at the centre of attention for multilateral agencies and critical scholars. While policy communities play important roles in developing urban sustainability as a high-level strategic response, this chapter shows that there is also an important underlying base of scholarly and practical engagements with urban sustainability. By tracing these engagements, this chapter draws together different disciplines and literatures and demonstrates how they simultaneously coalesce and diverge with respect to urban sustainability. This is an innovation in the existing literature from different disciplines, which, while all equally relevant to the evolution of urban sustainability as a concept, often fail to indicate the overlap in any particular context. Three intersecting insights emerge from this chapter's analysis:

1. The policy–science nexus

The momentum of urban sustainability policy demonstrates the role of multilateral institutions in driving and communicating urban sustainability as a type of collective action problem (Oels, 2005: 196). The history of UN processes shows policy mandates emerging to address an increasingly Global South agenda (UN-Habitat, 2014). At the time of writing, the most recent articulation at the global level of the "new sustainable development agenda" is the UNs Sustainable Development Goals (SDGs), which communicates "a set of goals to end poverty, protect the planet, and ensure prosperity for all" (UN, 2015a and b).

Some perspectives argue that urban sustainability offers an umbrella under which policy-makers, practitioners and theorists can roll out their own particular narratives or "storylines" (Hajer & Versteeg, 2005: 177). This chapter shows, however, that beneath the narrative, an intimate relationship exists between policy and science networks. As urban sustainability emerges increasingly in policy, indicating some degree of collective value shift, the important underlying base of critical discursive work by scholarly and practitioner communities informs the wider narratives and concepts.

This policy–science nexus relates to what Haas (1992: 3) terms "epistemic communities", or networks of professionals with expertise and competence in a particular domain and policy-relevant knowledge area. Understanding these domains is important not only for backing analysis with the relevant theory, principles and criteria, but also for indicating the trajectory of urban sustainability as a general concept. The analysis shows that along with changes in the policy lexicon and narrative, there is a growing interest in how cities function, highlighting urban infrastructure and services as key agendas for future engagements. These agendas in-turn are nuanced in terms of the role of practical experiments in the wider policy and conceptual shifts of urban sustainability.

2. Infrastructure and pilot projects

A second insight from this chapter is the increasing relevance of urban infrastructure as a strategic element of urban sustainability. The UNEP-IRP *City-Level Decoupling* report (2013) is perhaps the most recent and clear articulation from policy contexts of using urban infrastructure as a strategic mechanism for sustainability. There is a history of experiments in cities that indicate successful sustainability strategies can be local responses to practical urban management issues, particularly around infrastructure and provision of services. Indeed, many of the theoretical and conceptual engagements with urban sustainability draw on these practical sustainability experiments as key repositories of evidence and means for validation.

3. Urban services as common ground

As urban sustainability discourses engage with urban infrastructure, a fundamental question is: what do sustainability objectives mean for basic urban functions or services, such as water supply or sanitation, in terms of sustainable resource use or climate action? The proverbial “end-of-the-pipe” is a useful concept for using infrastructure services to examine urban sustainability shifts. Figure 1 puts foreword a generic heuristic for defining urban infrastructure in terms of a service delivery interface for examining sustainability. While acknowledging that there are complex components behind the “black box” of infrastructure (Winner, 1993), the heuristic is purposefully simple to highlight urban services in a way that societies and planners commonly interpret the functions of infrastructure. In Chapter 3, this framework is applied to urban water infrastructure to understand the history water functions over time. In Chapters 4 and 5, the framework is used do reveal the invisible work behind the “black box” of infrastructure.

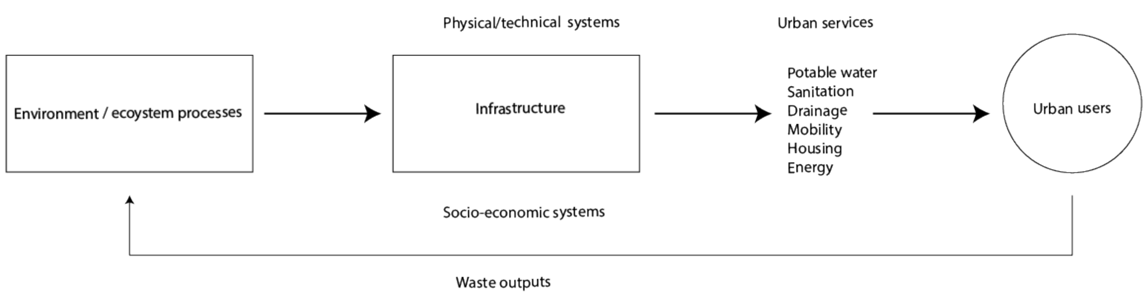

Figure 1 A generic service delivery interface

Chapter 3: Urban infrastructure

3.1 Introduction

"Urban infrastructure' is an umbrella term for how cities provide some of their most basic functions. Urban environmental history narrates this story, exploring how cities evolve over time in terms of the physical and social systems that are key to their functioning (Tarr, 1979; Jacobson & Tarr, 1994; Melosi, 1993; Rosen & Tarr, 1994: 301). Joel Tarr captures the essence of this with his metaphor of the "sinews" of a city, describing the roads, bridges, water and wastewater lines, disposal facilities, power systems, communication networks and buildings (Tarr & Dupuy, 1988, xiii). Another scholar in this field, Martin Melosi, examines water supply, sewerage and solid waste services in his poignant reflection on the rise of "sanitary services", *The Sanitary City* (2000).

Positioned within the general discipline of urban environmental history, this chapter develops the trajectory of urban water infrastructure, as well as the related philosophical and theoretical ideas that emerged, and which have a particular role to play in the evolution and practice of sustainability. Although ancient civilizations such as the Roman Empire and the Nasrid Dynasty had sophisticated water supply systems, the trajectory detailed here begins from the start of the industrial revolution, a critical period for how large urban areas approach water supply, and extends to the environmental movement in the late twentieth and early twenty-first century. These contexts are crucial for understanding recent calls for Sustainable Urban Water Management (SUWM), which, proponents argue, is an "evolution" in society towards concern for community well-being, ecological health and sustainable development (Marlow et al, 2013: 7151).

This chapter also extends existing urban environmental histories, using perspectives from critical geographers and scholars of sustainability transitions, which offer nuances useful to the study of infrastructure over time. In critical geography, the relationship between infrastructure and political economic structures is an important perspective in terms of differential access to water infrastructure (McFarlane & Rutherford, 2008; Gandy, 2006; Lefebre, 1991). This is the crux of Graham & Marvin's influential volume, *Splintering Urbanism* (2001), which reflects on the exclusion, customization and privatization of infrastructure in creating the "fabric" of "modern" cities.

An additional perspective on environmental history comes from Graham's *Disrupted Cities* (2010), which challenges the assumption of infrastructure as an invisible, ubiquitous part of a city. Graham's work foregrounds the hidden flows of resources, practices and technologies, which form the infrastructural backdrop to a city (2010: 2, 10). Specifically, his exploration of how these flows and processes break down in iconic infrastructural failures is useful in understanding the fragility of service delivery systems in the face of physical pressures, such as climate change or resource shortages (Graham & Marvin, 2001: 21-23).

Beyond theory and normative policy, this chapter demonstrates how a series of pilot projects in the US play a fundamental role in overturning ideas about infrastructure function in cities. These unique natural drainage experiments take place largely out of the immediate ambit of policy agendas and sustainability theory. While the history of urban water experiments is not limited to the US, natural drainage pilots in the Pacific Northwest and at *The Woodlands* in Texas demonstrate multiple benefits and are consequently formative influences that shape notions of, and attractions to, green infrastructure.

Some transition scholars with roots in urban environmental history take a particular interest in sustainability as a recent transition to systemic innovation, which represents both social and technical evolution (Kemp & Van Lente, 2011; Hodson et al, 2012: 294). A host of impressive analyses examine how sustainability transitions happen through the coevolution of technological functions and social functions and interests (Hodson et al, 2012; 294). While the purpose of this chapter is not to dissect this theory, the idea of a sustainability transition is a useful prompt for critically reflecting on various proposals for sustainability and integrated management in the urban water sector (Marlow et al, 2016: 1; Brown et al, 2008: 1; Furlong et al, 2016; Mitchell, 2006: 590).

3.2 Urban water infrastructure: A historical trajectory

3.2.1 The extended industrial revolution: 1850–1930

The extended industrial revolution is a period of major industrialization and urbanization between 1850 and 1930, largely in North America and Europe (Melosi, 2000: 7; Pieterse, 2008: 26-18). Initially, industrializing cities draw on rainwater and local surface water bodies, such as canals or rivers, and groundwater sources, such as wells or boreholes (Geels, 2005: 371; Kennedy et al, 2007: 47; Tarr, 2016). The rapid growth of industrial urban settlements means that local water sources quickly become insufficient, triggering the search for water sources beyond city boundaries (Kennedy et al, 2007: 47; Gandy, 2002: 30). Smith reflects that the shift from individuals using disparate local water sources, to sharing water supplies from centralized systems, is one of the most profound moments in the process of urbanization (2013: 55).

International examples are numerous. Local springs, shallow wells and rainwater collection systems are inadequate in Paris by the late eighteenth century, leading to the construction of one of the first major water systems of the era, the Canal de l'Ourq, beginning in 1802 (Sedlak, 2014: 34). In 1837, New York City, unable to use the brackish Hudson water, constructs the Croton System, and later, several distant water transfer systems replace local ponds and wells for public supply (Van Burkalow, 1959: 369). In 1934, in California, the Hetch Hetchy system, consisting of a 167-mile gravity-fed network, transports water to San Francisco from the Tuolumne River near Yosemite Valley (SFPUC, 2005: 4).

For cities aiming at city-wide water distribution, the need to draw on water resources beyond the immediate location of demand requires centralized waterworks, major storage facilities, and effective distribution networks (Sapkota et al, 2016: 4). The examples from Paris, New York and San Francisco show that supply augmentation is increasingly from further and further afield as demand outstrips available local supplies (Brown, 1998: 308; Sapkota et al, 2016: 4; Kennedy et al, 2007: 47; Gandy, 2002: 30).

The pace of urbanization during the industrial revolution often creates investment challenges for cities, where infrastructure connections may exist for older inner cities, but not for rapidly developing peripheral suburbs (Cooper, 2007: 20). City connections to main water networks are usually more challenging in dense urban fabrics, which require expensive overhauls because of existing infrastructure (Geels, 2005: 382, 390).

Industry is not only one of the largest water consumers, it also plays a significant role in the development of water infrastructure: ever-greater supply schemes are often developed to satisfy the demands of growing industry (Smith, 2013; Kaushal et al, 2015). Prior to later agendas of city public health, the influence of industry on water infrastructure is evident from the fact that the delivery of water supplies in cities is initially largely dominated by private companies, due to a prevailing laissez-faire attitude on the part of city authorities. Private water supply companies are already present in eighteenth century London, and they play a key role in driving technical innovation, such as the hydrological engineering that enables pump outlets to replace the previous gravity-fed system in the River Thames (Sedlak, 2014: 28, 1; Tempelhoff, 2003; Perard, 2009; Tomory, 2014: 2-3). In the twentieth century, post-war fiscal pressures also mean that private companies are better able to take on the financial risks of developing waterworks in an otherwise unfavorable environment (Geels, 2005: 37; Smith, 2013: 58; Gandy, 2002: 30; Tempelhoff, 2003).

In practice, while there are often partnerships between city authorities and private interests at some stage of the water delivery system, private water companies often play a foundational role in establishing the supply networks of industrial cities. During its gold mining boom, the City of San Francisco delivers water from the San Francisco waterworks using engineering services and employees from the Spring Valley Water Company (SFPUC, 2005: 8). Similarly, the Johannesburg Waterworks Exploration Company in South Africa, under the ownership of mining magnate Barney Barnato, emerges through a concession contract in the late 1880s (Turton et al, 2006: 360). Such contractual structures usually begin with government, or some government entity, issuing a concession or license to a private sector entity to develop a project (Gunawansa, 2010). These are also often long-term partnership contracts, which perpetuate private sector management of water supply infrastructure under government ownership (Bakker, 2003: 328; Gandy, 2011: 132).

In addition to supporting fast growing industry, water companies realize a profit incentive either by free competition, monopolization or structuring the market. In industrializing Baltimore, for instance, the first private water corporation delivers piped water to affluent suburbs or business districts while poor districts rely on water from shallow wells, often of inferior quality (Tarr, 2016). Critical geographers thus often highlight the historical fragmentation and spatial differentiation of urban infrastructure, and how service delivery, in turn, reproduces socio-economic inequalities (McFarlane & Rutherford, 2008: 364).

There are striking examples from colonial empires that show how biases in new distribution networks reflect racial and xenophobic prejudices. The British idea of "islands of purity" in nineteenth century Bombay (now Mumbai) is one of the most salient examples of the ring-fencing of infrastructure for colonial elites and the comparative lack of infrastructure for local populations, resulting all too often in catastrophic public health conditions (McFarlane & Rutherford, 2008: 419-420; Gandy, 2004: 368). The high death rate among Hindus in India during the nineteenth century reflects the discrepancy between colonial law and local cultural practices, as well as elite ideas about sanitation (McFarlane, 2008: 415). The colonial government's reluctance to invest in a fair and adequate supply of water derives from the imperial stipulation that "internal improvements" in overseas colonies should benefit the European enclaves (Gandy, 2008). Delivery of water to "elite" households by private water vendors, using jerry cans or tankers, was common practice in imperial cities and their colonies, often at a higher per unit volume cost to the public water supply system (Bakker, 2003: 37).

A number of basic insights can be gained from a review of water infrastructure development in cities during the industrial revolution: Firstly, because potable water is essential for human survival, water supply infrastructure is the first major investment a city undertakes. Secondly, because complex augmentation schemes develop in response to inadequate local supplies, the overlapping influences of industrial expansion and technical innovation in the development of water supply infrastructure is significant. Thirdly, the rise of industry stimulates the establishment of private water companies, which are often industrial offshoots. Finally, decisions to use particular technologies define the infrastructure context of cities, as the examples from Paris, New York and San Francisco show (Melosi, 1993; Jacobson & Tarr, 1994; Schott, 2004; Tempelhoff, 2003).

The development of extensive, large-scale, centralized, city-wide water supply schemes, implies service delivery by simply "turning on the tap" (Kaushal et al, 2015: 4064; Melosi, 2000: 15). However, political-economic dynamics, and significant social ideas that structure access, challenge the assumption that water supply is a ubiquitous service. Melosi's influential history traces the rise of the sanitary movement that shapes water supply as a public health issue and gives rise to the sanitary functions of city infrastructure into the twentieth century (Melosi, 2000). Specific social conceptions play an increasingly significant role and to understand the emergence of these functions, it is useful to trace the rise of the modern city ideal of "pure" water.

The campaign for "pure" water

The industrial revolution is a significant era for industrial and technological advancement, but it also has significant negative effects on the standard of human living conditions. Pollution and leakage of industrial by-products, such as coal and chalk, into water bodies is a major cause of contamination that causes acute health catastrophes in many industrial cities (Smith, 2013: 13-14). At the end of the nineteenth century, Philadelphia experiences one of the worst outbreaks of cholera and typhoid, both spread by contaminated water, and in London, the rapid spread of cholera has its roots in the polluted River Thames and several connecting groundwater resources, with catastrophic effects (Pizzi, 2005: 31; Sedlak, 2014: 30).

In many industrial cities, often where households construct informal waste drains leading to local water bodies, human waste enters local agricultural fields or cesspools without treatment (Kaushal et al, 2015: 4073). Some households use privy vaults, which are "essentially holes in the ground, often lined with stone, located close by residences, or even cellars" that spill over into cesspools (Tarr, 1979: 309). Households are usually responsible for periodically emptying and cleaning their own cesspools and privy vaults, or they might use private contractors and other third-party actors, but evidence shows this is often neglected (Tarr, 1979: 309; Geels, 2005: 1073; Daigger, 2009: 809).

Various perspectives on the deterioration of public health conditions emphasize the absence of regulation as a contributing factor – technologies to mitigate contamination are usually costly and initially difficult to implement at city scales (Smith, 2013: 13-14; Luckin, 1986; Hamlin, 1990). A key observation is that health conditions most often deteriorate before ideas emerge of water as a public health issue, in general, and waterworks as a "public enterprise", in particular (Melosi, 2000: 259).

Carl Smith's influential water histories document the failures of private companies to guarantee a dependable supply of "pure" or "good" water (Smith, 2013: 57). In his analysis of the disease outbreaks under the Manhattan Company in late nineteenth century New York, Matthew Gandy identifies a growing role for government in water delivery. This validates public health as an issue for "modern government" (Gandy, 2006: 16, 2002: 70).

The emergence of municipal waterworks and public water boards is an important historical development that reflects a social response to the failures of private companies (Smith, 2013: 14; Gandy, 2006: 18; De Graaf & Van der Brugge, 2010: 1283). Providing access to water services typically requires annexation or consolidation of the central city, in order to develop the necessary tax base to fund large-scale supply (Louis, 2004: 309-310). Planning developments relating to the rise of the municipality also have an influence. Planning innovations, such as eminent domain and municipal bonds, enable cities to plan more formally, and raise the capital for large engineering projects (Gandy, 2006: 17).

The large-scale waterworks and transfer schemes that emerge during the industrial revolution demonstrate how cities tackle their campaigns for pure water in the creation of a modern "networked city" (Graham, 2000: 184). Municipal waterworks are salient representations of how cultural notions of pure water intersect with the "modern city ideal" of centralized or city-wide infrastructure that provides limitless supplies (Melosi, 2008: 260; Brown et al, 2008: 6; Bakker, 2013; Smith, 2013: 14; Van Burkalow, 1959: 369). The development of municipal waterworks is an important context in the onset of what geographers term "hydro-social" contracts (Bakker, 2013; Gandy, 2002: 70), though there are certainly caveats to how these visions manifest, especially in terms of unequal access (Lees, 2004). Though theoretical to some extent, these contracts exemplify how changing expectations about water and social progress intersect with shifting dimensions of power and governance (Swyngedouw, 2007).

The sanitary movement and sewers

The industrial revolution plays a formative role in how water supply emerges as a fundamental infrastructure function in cities, although modernist ideals and emerging ideas of "pure" water take hold more specifically during the sanitary movement and later into the twentieth century. The sanitary movement crystallizes ideas of pure supply, and is significant in shaping public health as an urban agenda and motivating the extension of infrastructure's sanitary functions through the development of sewers. The sanitary movement first arises in the UK, and later spreads to the US, in response to worsening public health conditions in industrial cities (Gandy, 2002: 70; Tarr, 1996: 321). Overcrowding and unhygienic conditions are common in dense urban areas, especially in tenement housing, reflecting the deficits of sanitary facilities (Geels & Kemp, 2007: 448; Kaika & Swyngedouw, 2000: 136; Neumann & Smith, 2010: 24-25).

In some cities, human waste is sold onward as fertilizer to farmers (Geels, 2006: 1073), particularly in Europe where the reuse of human waste for land application has a long history. Sewerage farms exist outside major cities, including Paris, London and Zurich (Lofrano & Brown, 2010: 5259). Many of these systems suffer under intersecting demographic and environmental issues, such as odor control, and various health issues that derive from massive increases in human waste outputs during a city's industrial growth (Lofrano & Brown, 2010: 5259-5260; Tarr et al, 1984: 229).[4]

As health issues mount, the sanitary movement gains traction through the influence of public health discourses such as the miasma theory, filth theory and bacteriology (Tarr, 1979: 309; Tarr, 1996: 6; Gandy, 2002: 70; Schultz & McShane, 1987: 395). The miasma theory is especially influential in shaping sanitary reform to "flush disease-bearing dirt and foul odors away from urban populations" (Neumann & Smith, 2010: 24). Together with earlier industrial campaigns for pure water, the sanitary movement is influential in triggering a cultural shift away from the use of privy vaults and cesspools (Schultz & McShane, 1987: 395; Lofrano & Brown, 2010: 5259-5260; Tarr et al, 1984: 229).

In *The Sanitary City* (2000), Melosi relates the influence of the sanitary movement on the trajectory of urban water infrastructure in creating "environmental" or "sanitary services" (2000: 1). He views sanitary services as water supply, sewerage and solid waste disposal, arguing that these specific functions emerge as cities make efforts to sanitize their environments (Melosi, 2000). There are also influences from new technologies, such as the flushable toilet, that drive new industries and plumbing services, reaching a zenith later in the "bathroom mania" of the 1930s (Cowan, 1976: 6; Neumann & Smith, 2010: 24; Troesken & Geddes, 2003: 3741; Geels, 2005: 372; Tarr, 1996: 4; Kaushal et al, 2015: 4073).

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[4] Paris reuses human waste as fertilizer, termed 'poudrette', on sewage farms to grow crops. Sewage farms cease to operate as a result of concern over odors, and with the advent of chemical fertilizers and the increase in sewerage output beyond fertilizer production capacity. Human waste is then disposed of into the River Seine (Sedlak, 2014: 32-37).

In the nineteenth century, many cities begin replacing open channels, previously running down the center of streets or beyond household properties, with sewers and gutters under sidewalks or roads (Burian & Edwards, 2002: 9). Historical evidence shows that initially, some cities utilize sewers exclusively for draining runoff and continue to discharge sanitary wastes to privy vaults and cesspools (Burian & Edwards, 2002: 10; Geels, 2006, 1074). The combined sewer system or "sewer drain" is evidently first used in nineteenth century London, after severe cholera epidemics trigger vociferous political debate calling for innovation to address water quality and health concerns (Brown et al, 2008: 6). Combined sewers combine two purposes: the removal of both human waste or sewerage, and stormwater. The conveyance of mixed wastes, including industrial effluents, creates ideal conditions for the emergence of cholera.

Historically, combined sewers reflect the dilution-and-conveyance paradigm in water-carrying systems. Underground channel systems transport human "waste" water as quickly as possible away from populations and households, often with little or no treatment. The combined sewerage system disposes of waste effluent and rainwater outflows outside cities, into "environmentally benevolent" waterways (Kaushal et al, 2015: 4065, 4070; Brown et al, 2008: 6; Finewood, 2016: 1007; Burian & Edwards, 2002: 10). The combined system is appealing for dense cities – laying an additional pipe would be more disruptive of existing infrastructure such as street networks (Tarr, 1979: 309).

The sanitary movement is also an important statement, culturally, by an industrializing society about emergent perceptions of hygiene. "Public health" is a new social value in which "the government" plays a key role in what was formerly the individual's own responsibility (Geels, 2005: 372). Social perceptions of "dirty" and "clean" differentiate social classes into the "common" and the "elite" (Kaika et al, 2000: 136; Geels, 2005: 378).

Sanitary reformers often also function as city planners and play a major role in the creation of municipalities (Peterson, 1979: 84; Gandy, 1997: 341; Gandy, 2002: 70; Schultz et al, 1987: 397). The continual increase in human waste outputs in an industrializing city creates wastewater flows that require onward conveyance, drainage and treatment. Sanitary engineering, later morphing into the civil engineering profession, is key to the institutional capacity of municipalities (Grigg, 2001: 371).

The "hardscaping" of previously permeable surfaces with impermeable surfaces is one of the effects of urbanization. Rainfall is no longer able to penetrate and local ditches or streams cannot absorb rising runoff volumes, increasing runoff coefficients and thus peak flows (Burns et al, 2012: 230).[5] Conveying rainfall runoff in sewers highlights cities' responses to the hydrological effects of urbanization as well as social perceptions of rainfall runoff. The appearance of the term "stormwater" in the early twentieth century reflects cultural perceptions of how runoff from rainfall essentially becomes unwelcome wastewater in cities, and concerns about flood risks emerge (Hill, 2009: 15; Baker, 2009: 10; Burian & Edwards, 2002: 12; Finewood, 2016: 7).

There is a gradual shift towards a separation of sewers. Cities increasingly lay one system of pipes for draining stormwater to local surface water bodes, and a sanitary pipe system that carries human wastes, ideally to treatment works (Burian & Edwards, 2002: 10; Finewood, 2016: 8; Hill, 2009: 150). The change to a dual system stems from a combination of factors (see Tarr, 1979). Sanitary reformers such as George E Warring advocate sewer separation to improve water quality and address health challenges since it is more efficient at removing wastes away from development than the combined system (Tarr, 1979: 316; Tarr et al, 1984: 237; Burian & Edwards, 2002: 10). Concern over Combined Sewer Overflows (CSOs) is a major trigger for separate sewers because, in particularly acute wet weather conditions, a large volume of untreated sewage can be discharged into water bodies (Hill, 2009: 150). This is evident in the critical state of the River Thames in nineteenth century London and several cities in the US using the combined system (Finewood, 2016: 18; Gasperi et al, 2010: 5876; Hill, 2009: 150).

The separate sewer system most often uses a small-diameter pipe for household wastes (the sanitary sewer) and a larger diameter pipe for stormwater from streets, roofs, and yards, although this is not always the case (Tarr, 1979: 309). Some smaller industrial cities evidently lay sanitary sewers without providing for underground removal of stormwater, so this essentially becomes a combined system during heavy precipitation events (Tarr, 1979: 309; Tarr et al, 1984: 237).

Studies in the US indicate CSO continues to be a major cause of water quality problems for receiving water bodies since combined systems persist in several cities into the twentieth century (Hill, 2009: 150), but the separate sewer system is an important historical trend towards functional separation of "sewerage" and "stormwater" infrastructure. The sanitary movement is a strong influence on embedding these functions, first in the combined system, which serves a dual purpose, and later in the separate system. While there are caveats to this trend, the sanitary movement's ideas about purity and the need for sanitary environments has a fundamental effect on the emergence of water supply, sewerage disposal, stormwater management and drainage

[5] Many communities, particularly in the Mediterranean climates of Southern Europe, collect and store rainwater in cisterns as an important water supply resource (Chocat et al, 2007: 274).

functions in cities. These functions develop on a new scale with the rise of high modernity towards the mid-twentieth century.

3.2.2 High modernity": 1930s–1960

Bulk water supply

The period from approximately 1930 to 1960 can be regarded as the era of "high modernity" when Keynesian and Fordism rise as powerful ideologies (Kaika & Swynegedouw, 2000; 132). A cornerstone of these ideologies is leveraging infrastructure as a key mechanism for creating the "modern" city ideal, as manifest in the US and Europe (Graham & Marvin, 2001; McFarlane & Rutherford, 2008: 363). A "golden era" of public works promotes dense infrastructure investment in cities as a means of fuelling fuel post-World War II development and realise Keynesian "welfarist" aspirations (Kirkpatrick & Smith, 2011: 480).

In the US, the context of the New Deal and increasing federal prominence drives investment into large-scale capital projects to stimulate economic development and job creation (Louis, 2004: 315). Similar Keynesian trends emerge during the 1930s in Europe where substantial state intervention aims to promote economic development and better living conditions (Healey, 2007: 29). With growing urbanization, a new democratic project also develops to provide every citizen with the "rights to cheap, good-quality and accessible infrastructure and services" (Guy & Marvin, 2001: 29).

Keynesian aspirations are significant in setting large global public works infrastructure projects in motion, such as large dams, aqueducts and trans-boundary pipelines (Wolman, 1965; Graham & Marvin, 2001). Use of the term "bulk" for water resources development, referring to the onward transportation, treatment and distribution of large quantities of potable water to urban communities, is indicative of the developing supply augmentation paradigm (Baker, 2009: 1l; Bakker, 2003). A wide shift towards national utility grids from the 1930s onwards reflects Fordist strategies of driving capital accumulation through the development of infrastructure and bulk supply systems (Graham & Marvin, 1994; Grigg, 2005; Grigg, 2002: 167; De Graaf & Van der Brugge, 2010: 1283; Bakker, 2003: 35-45; Gandy, 2004: 368).

Bulk supply networks are a major driver creating the "consumption cities" of the first wave of urbanization (Swilling, 2011: 83; Swyngedouw et al, 2002: 127; Wolman, 1965: 163). The resource intensity of large-scale water distribution is evident in New York, where groundwater withdrawal from the late 1930s causes a significant drop in the water table (Van Burkalow, 1959: 382). The recognition of over withdrawal results in 1947 legislation to prevent pumping from Brooklyn's Flatbush wells. The onward effect of switching to Catskills water arguably does not alleviate the overall problem, however (Van Burkalow, 1959: 383).

The large dams and pipes systems of the twentieth century are part of the "hydraulic mission" of aggressive water supply augmentation (Turton et al, 2006: 235; Meissner & Turton, 2003: 116). The formation of centralized networks in cities as supply-side solutions to society's water needs is part of a wider paradigm of bulk conveyance that also manages the increasing sewerage and stormwater flows in urban areas towards the middle of the twentieth century.

Bulk conveyance

The increase in wastewater flows from the growing number of potable supply connections revives earlier calls to remove "sanitary nuisances" from urban areas (Swyngedouw et al, 1978: 127; Jacobson & Tarr, 1994: 14). While some older cities continue to utilize sanitary sewers to reticulate rainfall runoff in one combined pipe for onward reuse from approximately the 1930s, the preference is increasingly for separate systems with centralized sewers as part of a bulk wastewater conveyance network, a more formal infrastructure function for more efficient removal, often with little or no further attention (Burian et al, 2000: 47; Burns et al, 2012: 230; Chocat et al, 2007: 273; Kaushal et al, 2015: 4069; Melosi, 2000; Kennedy et al, 2007: 49). Generally, centralized sewers convey wastes in a wastewater stream to a distinct facility for onward conveyance (Tarr, 1979: 312). In Sweden, the total pipe-length of cities' centralized water and sewer systems increases significantly, from about 3 500 km at the end of the nineteenth century to approximately 10 000 km in 1944 (Cettner et al, 2012; Isgard et al, 1987).

While the conveyancing system generally collects human wastes efficiently, the dilution approach means enormous volumes of raw or minimally treated wastewater dispose into water bodies (Jacobson & Tarr, 1995: 14). Where wastewater treatment techniques do exist, they are not always entirely effective. More advanced technologies are usually expensive and often require system overhauls that are challenging for dense cities. The general absence of appropriate water-quality legislation is also an underlying issue (Cooper, 2007: 27; Lofrano & Brown, 2010).

The age of the automobile as a consequence of the industrial revolution is a significant influence on spatial sprawl and outward urban expansion. Changing financial and economic patterns also have an influence: mortgage securitization and other credit provisions give access to credit for physical real estate purchase and development, often of low-cost land on the "urban fringe" (Bieri, 2013: 8; Kelbaugh, 2014: 70; Fishman, 2011). A dramatic shift of development away from San Francisco and Oakland to smaller cities around the Bay Area in California during the 1950s (Dowall, 1982: 718) is indicative of the emergence of the suburb as a common spatial form, part of a trend, more broadly, towards poly-centric regions (Tarr, 1994: 43, 47; Dowall, 1982: 722). Growing urban development has major spatial and hydrological implications for urban drainage. While urbanization is already underway earlier during the industrial revolution, the scale of sprawl during high modernity significantly reduces capacities for runoff attenuation and interception (Kennedy et al, 2007: 49) since sprawling urban development typically includes a growing area of impervious surfaces, effectively hardscaping over vegetation and compacting soil strata (Burns et al, 2012: 230).

In the mid-twentieth century, stormwater management is largely concerned with the development of drainage channels, pipes and sewers, generally along with impervious asphalt or concrete surfaces (Hill, 2009: 157; Mell, 2009: 27; Kaushal et al, 2012: 409; Elmore, 2008: 308). This constitutes "conventional" or "traditional" stormwater management. This sort of bulk conveyance results in what Geneletti terms "linear" infrastructures that fragment or "cut through" existing landscapes (2004: 3). In Berkeley, California, the depression-era Progress Works administration encloses all remaining open reaches of Strawberry Creek in line with public health and flooding concerns (Charbonneau & Resh, 1992: 295), and in Pittsburgh in the 1950s, the routing of watercourses into pipes, culverts and concrete channels results in the disappearance of lower order main streams (Finewood, 2016: 8; Weitzell et al, 2016: 1; Benedict & McMahon, 2002: 12; Elmore et al, 2009: 308).

The concept of "linear" infrastructure relates to Wolman's idea of metabolism that describes the throughput of resources and materials after extraction from the natural system as inputs for creating products and services for human use (Wolman, 1965; Niza et al, 2009: 385). The description of infrastructure as "linear" also refers to extraction of the supply-side resources necessary to support urban activities, while depositing wastes in high concentrations back in the external environment (Hodson et al, 2012: 793; Brown, 1998: 308; Gandy, 2006: 17; Gleick, 2003: 291; Daigger, 2009: 809).

As a consequence of the paradigms of bulk water distribution and wastewater conveyance, "grey infrastructure", that is, the built, engineered or man-made infrastructure of roads, buildings, pipes, sewers, wires and utility lines, becomes ubiquitous during high modernity (Mell, 2010: 57; Pincetl, 2010: 44; Benedict & McMahon, 2002: 12; Wolf, 2003: 141). Use of the term grey infrastructure is essentially a social commentary on the types of materials, such as concrete or steel facilities and conduits, that typically comprise engineering infrastructure (Wright, 2011; Mell, 2013:

156; Wolf, 2003: 141). Habitat destruction and water quality degradation result not only from the use of impervious materials, such as concrete, but also from channelization. The impact of grey stormwater infrastructure is regarded as particularly negative because of the tendency to replace free-draining surfaces, such as vegetation, with impervious concrete or cement surfaces, and reroute stormwater into canals or underground by-pass culverts (Charbonneau & Resh, 1992: 295), supposedly for drainage efficiency (Cettner et al, 2012: 36; Fletcher et al, 2014: 4; Bacchin et al, 2014: 3).

Stormwater is a primary vector for numerous pollutants, so that identifying the origins of non-point pollutants, such as heavy metals from rooftops, and fertilizers, is particularly complex (Kaushal et al, 2011: 8230). Misconnections between different grey infrastructure systems such as leakages between sewer and stormwater lines, which may create multiple levels of contamination, are potentially also an acute pollution issue (Elmore et al, 2009: 308).

In urban water drainage histories, a focus on "damage control", with the primary goal of controlling runoff, typically fails to consider other functions and environmental externalities such as water quality and ecological integrity (Ahern, 2007: 275).

3.3 The ecological turn in urban planning and design

3.3.1 The environmental movement: 1960s–2000s

For most of its history, urban water infrastructure is in conflict with the natural environment and often bears the brunt of environmentally-concerned criticism. A number of developments in the mid to later twentieth century reflect changing attitudes to society and the environment and traditional perspectives shift. Anti-war protest action groups in the US during the 1960s and 1970s join environmental movements in calling for political and social reform (Melosi, 2000: 291; Rosen & Tarr, 1994: 306; While et al, 2004: 550). Modernist planning is condemned as a paradigm of rationalist management and overt structuralism that fails to appreciate social context, diversity, and the complexities planners face in their everyday practice (Habermas, 1989; Innes, 1994; Allmendinger, 2002; Healey, 2007). Jane Jacob's *The Life Death and Death of Great American Cities* (1961) embodies the discontent, particularly following Fordism and High Modernity, with the destruction of economic and social diversity (1961: 13-14). In 1962, Rachel Carlson's environmental science book, *Silent Spring,* castigates the industrial system for the "irrecoverable pollution" of the earth (1962: 6).

There is a particular revolt against the "city junkyard", where the historical binaries nature and society struggle against each other (McHarg, 1969: 23). The industrial revolution is derided by critical socialists and eco-feminists, among others, for establishing "mechanistic" approaches to urban functions that dominate nature (Marx, 2000: vii; Merchant, 1998: 282). New ecological philosophies to overturn the domination of nature by humans are called for (Marx, 2000: 2; Lynch, 1960; White, 1967: 6; Merchant, 1980: 78; Walsh, 1993: 50; Naess & Sessions, 1984: 3).

The search for a new urban aesthetic and function challenges nineteenth century strategies that attempted to address pollution and provide public amenities to improve the mental health of the newly urbanizing citizenry, such as city parks and gardens (Dennis & McIntosh, 2013: 39; Fishman, 2011: 33). Iconic projects such as New York's Central Park, the work of Frederick Law Olmstead and Calvert Vaux in the late 1800s, are criticized as ecological determinism and no more than a superficial engagement with landscape (Whiston Spirn, 1988: 108; Mozingo, 1997: 46). Central Park was intended to be the "lungs of the city", and a counterforce to the overcrowded, cramped and over-gridded city experience (Dennis & McIntosh, 2013: 43; Fishman, 2011: 32-33; Kunstler, 2013: 30). Olmstead's subsequent work, such as *The Emerald Necklace* in Boston (also late 1800s), incorporates parkway plans in development strategies for expanding cities and proposes the functional use of unified parks at the urban edge for balancing the development of built fabric with open space (Hosgor & Yigiter, 2011; Dennis & McIntosh, 2013: 45). The parkway paradigm could be extended to regional scale using interconnected park systems for structuring the direction and flow of city form (Dennis & McIntosh, 2013: 45; Fishman, 2011: 33). The *Garden Cities* concept of Ebenezer Howard and Raymond Unwin, although stifling to social and ecological diversity, exhibits, in theory, the principles of walkability and mixed-use design (Asabere, 2012; Batchelor, 1969; Howard, 1902; Ross, 2014).

In the twentieth century, scholars such as Anne Whiston Spirn criticize these nineteenth century "large green projects" as manifestations of "nature" that ignore underlying natural processes (1984, xi, 31-36). What Kristina Hill terms "designer-academics" play a crucial role in greater ecological awareness in planning (2009: 146)[6] and bringing "nature back in" (Busch, 1996: 491). These contributions are part of a lineage of struggles by scholars and practitioners to provide meaning by engaging with landscapes that are functionally relevant to society (Hall, 1991: 14, 18). Like Ian McHarg (see *The Woodlands*, below), Whiston Spirn seeks a new urban design aesthetic for overhauling

[6] Scholars in North America and Europe dominate the intellectual engagement with ecologically-oriented designs that are the "signs of changing values" (Hough, 1995: 1), encompassing "a matter of ethics" (Beatley et al, 1995 14-15), as applied to "[ingenuous] adaptions to nature" (Whiston Spirn, 1984: 10).

romantic associations of nature and expresses a concern with "city and nature" jointly (1984: 9). Joan Nassauer elaborates on how designs foregrounding the "scenic" or the "picturesque" undermine the improvement of ecological quality and health, which, she views as a cultural problem related to ecological function (1997a, also Nassauer & Opdam, 2008: 633-635). A precedent for addressing this relationship can be found in Kevin Lynch's cognitive mapping approach which seeks to represent the functional diversity of urban form as well as non-human aspects (1960: 91-98).

With the failure of modernism and a backlash against its social and ecological ills, a search for a new, more holistic, view of urban function emerges, integrating ecological and social function in urban planning and design. The specifics of this approach do not go uncontested, however. For instance, Kelbaugh comments that differences in opinion and deadlocks in sustainable design and planning thinking arise from differing definitions of urbanism, which create various preferences for visual form and aesthetics (2013: 69-72). This dilemma is central to the rise of *Landscape Urbanism* and the vigorous discourse about lack of transformation towards truly integrating ecological and social function (Duany & Talen, 2013). Underlying such debates, and indeed the history of the ecological turn in urban planning and design, is the recurring question of not only improving functional performance, but also articulating and evaluating a wider or more holistic view of urban function (Hill, 2009: 162).

The rise of the environmental movement is the US is significant for changes to the study of water infrastructure as well as water quality and environmental protection legislation. Dennis and Donella Meadows and colleagues influentially frame the notion of "environmental limits" during the 1972 oil crisis (Meadows et al, 1972), the same year as the first United Nations (UN) conference on Environment and Development (Burgess et al, 2003: 261). The National Environmental Policy Act (NEPA) (1970) mandates environmental impact assessments, reflecting the beginning of more robust regulation of development applications and processes (EPA, 2017). The Clean Water Act (CWA) (1972) and the Water Pollution Control Act Amendments (WPCAA) (1972) tighten water quality standards and, crucially, place responsibility for wastewater treatment at local level (Tarr, 2016; 11-12; Daigger, 2007: 677). Additionally, the Endangered Species Act (ESA) (1973) is influential in compelling cities to develop pollution control strategies and commit to other initiatives such as habitat restoration for the conservation of endangered and threatened species (EPA, 2017b).

The legislative changes in the US trigger a series of experiments in addressing water quality and environmental protection at city level. The scientific discipline of hydrology, the study of rapid and efficient conveyancing of stormwater out of cities, is formalized (Brown et al, 2008: 7). In parallel, "stormwater management" becomes a formal local government planning function, although often in association with other line functions, particularly road planning (Fletcher et al, 2014: 1; Grigg, 2002: 47). Where suburban, zoning and regional roads require drainage and flood control services, county departments begin to adopt stormwater management roles (Grigg, 2002: 47). As Strang (1996: 11) reflects, water infrastructure offers an accessible platform for understanding multiple benefits of natural systems and ecological principles. Stormwater management, becomes an unlikely ally in this regard. The need to control stormwater volume and flow rate, to limit overflow events and the deposition of sewerage in water bodies, is an important trigger for various natural drainage investments including rooftop treatment systems and bios-wales, among others (Hill, 2009: 150; Schueler et al, 2007).

Several American experiments show not only the potential for legislation to induce change, but also the important role that infrastructure practitioners working on natural drainage pilots can play in evolving concepts about infrastructure function. A full analysis of these experiments in the US and in other contexts such as Australia and Singapore (see Mitchell, 2006: 589; Bahri, 2012: 24-25), is beyond the scope of this dissertation, but a number of important case studies demand close attention.

The Woodlands, Texas, 1974–1976

This influential pilot project, initiated before much of the environmental legislation came into full effect, overturns the idea of single purpose infrastructure. It uses the natural drainage properties of existing floodplains, vegetation and site hydrology, reflecting Ian McHarg's philosophy of "letting nature do the work", articulated initially in his publication, *Design with Nature* (1969) (McHarg, 1969, 1973: 1-6; Burns et al, 2012: 231). McHarg rebukes the industrial city as lacking both the presence and the meaning of nature (McHarg, 1969: 19). *Design with Nature* is an opposition not only to unplanned urban growth, but also to modernist attempts to relate to supposedly natural values (McHarg, 1969: 216). McHarg criticizes the functionalistic–picturesque impulse of the early twentieth century park movement in designing for scenery rather than suitability for natural processes (McHarg, 1969: 216; Hauck & Czechowski, 2015: 10-12).

Before the project gets underway, McHarg engages in four years of discussions and negotiations with colleagues, planning consultants, corporations, universities and local communities, studying the Texan site in detail prior to applying a plan (Sutton, 1975: 325). *The Woodlands* site guidelines use the opportunities intrinsic to the site, such as the existing woodlands for drainage, to yield environmental benefits (McHarg, 1969: 1, 222; Spirn, 1984: xi, 9, 36; Hill, 2009: 145). The inclusion of vegetation, wildlife corridors, and pedestrian buffers, among other site connections, is a conceptual departure from previous drainage paradigms (McHarg, 1973). *The Woodlands* achieves "double savings", by avoiding "both the expense of an artificial drainage system and the expense of planting replacement trees" (McHarg, 1973: 1).

At a philosophical level, *The Woodlands* strategy's other novel approach to infrastructure stewardship is to challenge preexisting service practices. The design proposal title, *Woodlands New Community: Guidelines for Site Planning,* reveals the intention of relying on the community rather than a particular government agency or utility for infrastructure performance (McHarg, 1973). The project does this by linking private land parcels to public infrastructure (Hill, 2009: 145).

McHarg's general philosophy and community-based ecological methods of planning and experimenting with natural drainage options reshape ideas about infrastructure performance (Hill, 2009: 142; Strang, 1996: 11; Booth, 2005: 732). This natural drainage project is significant to the rise of ecological methods of planning that integrate natural processes and consider intrinsic site suitability in the US (McHarg, 1969: 216-222; Steiner, 2011: 533). The application of the "predevelopment hydrology" paradigm, which aims to replicate, as closely as possible, the natural drainage properties of a site, is influential in the adoption of ecological methods of site-design and catchment-wide approaches for Low Impact Development (LID) strategies (Fletcher et al, 2014; Burns et al, 2012: 231).[7] The application of Geographic Information Systems (GIS) to planning becomes the overarching framework for spatial data and analysis (McHarg, 1969, 222; Steiner et al, 2013: 356).

Seattle and Portland

Two alternative infrastructure projects in the pacific Northwest of the US evolve ideas about function and the processes of monitoring performance. Under the "damage control" mindset, infrastructure development in Seattle and Portland results in high pollutant concentrations of stormwater and the modification of natural habitats (Schott, 2004: 520; Sapkota et al, 2015: 164; Marsalek, 2013: 3; Hill, 2009: 161). There is some history of natural drainage practice and asset management in both cities, and a growing awareness of the concepts of green infrastructure begins to shift ideas about infrastructure function. Water quality and stream habitat restoration become priorities, in line with federal water quality requirements and conservation mandates from the Endangered Species Act (ESA)

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[7] Low Impact Development (LID) is the initial term for "natural drainage" techniques, which refers to the "use, building and infrastructure construction technologies that minimize the life-cycle environmental impact of constructing storm drainage and other public and private facilities" (SPU, 2007: 18). Later strategies mention Green Stormwater Infrastructure (GSI) as "the set of distributed stormwater best management practices that mimic natural systems", which largely supersede LID in the strategic lexicon (Seattle Public Utilities, 2015: viii; see also Fletcher et al, 2014: 8).

(1973) concerning wild salmon.

In the 1990s, Seattle Public Utilities (SPU) launches the Urban Creeks Legacy program to undertake urban creek restoration in an effort to protect the salmon (Wise, 2008: 2). However, stormwater planners at SPU realize that creek restoration is insufficient for salmon protection, and they then develop the Natural Drainage Strategy (NDS) (Wong & Stewart, 2008: 2). The NDS launches a pilot project to test alternative stormwater techniques and gain public support for replication (SPU, 2007; Hill, 2009: 152, 163):

> Seattle's receiving waters and aquatic life have been significantly impaired by the negative impacts of urban stormwater runoff. Increasing volumes of runoff also cause flooding of roadways and property. Traditional methods of stormwater management and street design have proven to be ineffective at countering the impacts of current and future development on receiving waters.
>
> [The] Natural Drainage Systems (NDS) is an alternative stormwater management approach that delivers higher levels of environmental protection for receiving waters at a lower cost than traditional street and drainage improvements (SPU, 2007).

While the quality of the environment is the primary focus, the NDS also articulates an important narrative about cost savings. As a result, Seattle launches the Street Edge Alternatives (SEA) project, which incorporates a variety of low-impact development techniques such as bio-swales to store and filtrate stormwater and capture pollutants for biological breakdown (SPU, 2007: 2; CNT, 2010: 23). In addition to bio-retention, SEA advocates roadway narrowing, the elimination of traditional curb gutters and the placement of sidewalks on only one side of the street (CNT, 2010: 23).

In Portland, the city metro also develops a stormwater program in the early 1990s, to address water quality and protect wild salmon and steelhead, under the influence of the National Pollutant Discharge Elimination System (NPDES) and the Municipal Separate Storm Sewer System (MS4) (WERF, 2009). The metro determines that culverts block salmon migration and that combined sewer overflows (CSO) have a significant impact on water quality in specific areas during wet weather events (Kloster et al, 2002: 1; Netusil et al, 2014: 15).

Later, in the early 2000s, a series of pilots forms part of the metro's *Green Street Program*, testing the viability of a "natural systems approach" that uses vegetative facilities to manage stormwater, reduce flows and improve water quality and enhance watershed health (Georgetown Climate Center, 2011). The *Green Streets* pilots also explore alternative infrastructure techniques in urban street design, promoting the use of public sites as models for upland water management (Hill, 2009: 156).

The Seattle and Portland pilots are important as experiments in alternative infrastructure approaches, and additionally, they demonstrate benefits beyond drainage, such as better water quality, habitat improvements and cost savings (SPU, 2007: 15; BES, 2010). Traditional "grey" systems tend to degrade over time, whereas, according to SPU, when viewed as a trajectory over a project's life span, the cost savings of natural drainage systems improve over time as vegetation matures (Wong & Stewart, 2008: 2). While many of the early SEA-streets are expensive investments upfront, with institutional learning, the costs of replication come down over time (MacMullan & Reich, 2007: 15).

The multiple institutional layers of these projects is significant for green infrastructure going forward. In *The Woodlands,* practitioners engage with universities and local communities in the preliminary work, as part of a wider community infrastructure management approach. The inter-agency relationships that form the backdrop of natural drainage pilots in Portland and Seattle reveal how practitioners leverage institutional relationships between government agencies to activate change. In Seattle, relationships between the capital planning unit at SPU and senior policy-makers and technical staff during the formative years of the natural drainage program are crucial to the later success of SEA-Streets (Hill, 2009: 152). SPU also engages with the University of Washington (UoW) in monitoring the SEA-Streets flow volumes and water quality outcomes (SPU, 2007: 8-9). In Portland, the *Green Streets Technical Advisory Committee* (GSTAC) includes a range of planners, scientists and engineers from various government agencies as well as the private sector (Kloster et al, 2002: 3; Georgetown Climate Center, 2011).

The pilot projects in Seattle and Portland are practical strategies by city engineers and utility staff in response to legislative mandates, as well as explorations of creative infrastructure financing options, and are, as such, largely outside the remit of sustainability policy and theory. However, together with McHarg's natural drainage experiment at *The Woodlands*, Seattle and Portland are important in terms of the rise of green infrastructure planning and implementation. While there are other important experiments with alternative infrastructure options, Seattle and Portland offer valuable insights about design choices and costs not otherwise available at full-scale (Hill, 2009: 156). Their value also extends to the particular methods, such as asset management and Life Cycle Analysis (LCA), that practitioners employ to evaluate function and measure project performance.

3.3.2 Monitoring, evaluation and financing

Methods for monitoring and evaluating project performance are critical to assessing a pilot project's degree of success, and specifically, its sustainability. The SEA prototypes monitor natural drainage strategies and design changes and demonstrate cost savings for the City of Seattle of approximately 15 to 25 percent when compared to conventional methods of stormwater control (CNT, 2010: 23). To measure these performance outcomes, SPU uses asset management models, essentially infrastructure management methods, to assist utilities with institutional education and determine service levels and capital review (IWR, 2013: 21-22).[8] Building on a LCA approach, SPU's asset management systems use Benefit Cost Analysis (BCA) to evaluate, model and report on the cost of project options (SPU, 2007: 15). The SPU is therefore able to demonstrate the combined value of SEAs, including social benefits such as traffic calming, ecological benefits, and financial savings (SPU, 2007: 15; SPU, 2002).

In Portland, the City's Bureau of Environmental Services (BES) documents the results of *Green Streets* pilots in a series of case studies that reflect total project costs in terms of economic, environmental and social variables (EPA, 2008: 9). The Sustainable Stormwater Best Management Program (BMP), a parallel process with support from a Sustainable Infrastructure Committee, provides the institutional space for investigating alternative infrastructure design options.[9] These project monitoring processes are fundamental to Portland's later *Grey to Green Program,* a comprehensive green streets policy promoting and incorporating the use of green street facilities in public and private development (BES, 2010: 1). In consultation with a panel of experts, the BES publishes *Portland's Green Infrastructure: Quantifying the Health, Energy, and Community Livability Benefits* (BES, 2010), a performance assessment that employs the concept of "ecosystem services" to communicate benefits beyond water quality, watershed health and wildlife habitat (BES, 2010). The global trend of assigning monetary values to ecosystem service categories is used to guide decisions and determine funding priorities for future green stormwater management investment (BES, 2010).

Encouraging investment beyond utility responsibility reflects the fiscal contexts of cities and the need to make the economic case for infrastructure in terms of "dollars and cents". The natural drainage strategies in Seattle and Portland undergo a shift in both terminology and investment focus. In 2015, Seattle launches a 5-year Green Stormwater Infrastructure (GSI) implementation strategy "diversifying Seattle's GSI portfolio", and

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[8] The US Government Performance and Results Act (GPRA) (1993) is concerned with management of government projects. While not focusing specifically on asset or property management, the GPRA defines a series of implementation approaches that mimic those of asset management. The United States Army Corps of Engineers (USACE) implements the GPRA and other federal requirements, and provides guidelines for a comprehensive asset management program (See IWR, 2013: 6).

[9] The metro's experiments earlier, in the late 1970s, with anti-sprawl measures or Urban Growth Boundaries (UGB) are also relevant in fostering strategic awareness about "compact, livable, neighborhoods". The UGB feeds into the metro's *Region 2040* plan that requires local governments to "regulate increasing residential densities, raise the number of street connections per mile, cluster development around transit and help to establish a regional greenspaces network" (Wheeler, 2003: 324).

categorizing integrated management of infrastructure as “voluntary, beyond code” retrofits (SPU, 2015: 32). The Seattle strategy envisions increasing investment by communities and other government departments and agencies in non-utility infrastructure (City of Seattle, 2015: 29). The initial approach of intervening in public spaces such as sidewalks, shifts across multiple scales and contexts to include residential, commercial and public land for increasing the portion of non-utility retrofits (City of Seattle, 2015: 19-31).

Portland uses public demonstration sites to test the viability of Business or Local Improvement Districts financing green infrastructure projects, where municipalities and private property owners share costs and maintenance responsibility (City of Portland, 2013). These developments indicate the shift not only in terminology, from natural drainage concepts to green infrastructure, but also in financing options, exploring alternatives such as land-based and local district financing.

Behind-the-scenes of the conditions and benefits of service delivery in infrastructure function projects, lie the practices of monitoring, evaluating and asset management (Cagle, 2003: 2). The evaluation of ecosystem functions or services (Tzoulas et al, 2007; Steiner et al, 2013: 360) is attracting a great deal of theoretical as well as applied research. The projects in Seattle and Portland demonstrate the critical role that methods such as LCA or BCA can play in the internal knowledge processes of infrastructure utilities and in tracking how infrastructure concepts evolves over time. More recently, the identification of asset management as a key tool for meeting international sustainability goals for infrastructure management shows how embedded and emerging knowledge methods operate at different planning levels in relation to future levels of service, identifying existing gaps, and informing operations and maintenance (Marlow et al, 2010: 1250).

Advancements in urban hydrology contribute to the development of technical capacities for monitoring multiple benefits (Booth, 2005: 724, 732; Schueler, 1994; Horner et al, 2004: 1; Schuler et al, 2007: 165; Pickett et al, 2008: 139). Other applied disciplines such as landscape architecture and urban ecology also contribute, for example, in methods for evaluating strategic landscape designs for combined goals (Johnson & Hill, 2002: 1; Hauck et al, 2015: 12; Hill, 2009: 143).

McHarg’s experiment at *The Woodland*s is an early indication of the power of landscape evaluation methods to assess infrastructure function. Following this precedent, the Landscape Architecture Foundation (LAF) develops the landscape performance case method, which measures the effectiveness of landscape solutions through ecological performance assessments (LAF, 2017; Johnson & Hill, 2002: 1; Collins et al, 2000: 416).

In concentrating on the outcomes of built projects, landscape performance assessments differ from market valuations, such as of ecosystem service quantifications, which are contentious on several ethical grounds (Yang et al, 2016: 315; Kosoy & Corbera, 2010).

Landscape architecture cases studies also emphasize the relationships between the policy and science communities that often support monitoring and evaluation. In Detroit, for instance, the local government association, SEMCOG, develops the technical, data and intergovernmental resources in association with the University of Michigan (Meerow & Newell, 2017; SEMCOG, 2014; City of Detroit, 2001). In some cases, the private sector plays a significant role, such as, for example, when the global engineering consulting firm, ARUP, provides the project support for London's *Green Infrastructure Task Force* (British Ecological Society, 2015).

3.3.3 Sustainability and the integrationist agenda

The reliance in "modern" industrial societies on large-scale and centralized management, and "limitless" supply augmentation projects transferring water to cities across increasing distances, is attracting growing criticism (Turton et al, 2006: 325). The discourse considers "traditional" management to be at odds with environmental objectives and no longer appropriate in the contexts of limited resources, ecological degradation, climate change, and the fiscal pressure associated with investing in future large-scale city infrastructure (Marlow et al, 2016: 1; Brown et al, 2008: 1; Hurlimann, et al, 2017; Furlong et al, 2016; Mitchell, 2006: 590). The need to evolve urban water functions away from just water supply, sewerage and drainage, to encompass a range of wider considerations (Furlong et al, 2016: 784; Marlow et al, 2013: 71) has given rise to the concept of Sustainable Urban Water Management (SUWM). This combines community well-being, ecological health and sustainable development in a "net benefit" approach to water infrastructure development, (Marlow et al, 2013: 7151).

The philosophy of "integration" takes issue with the traditional separation of water supply, sanitation and stormwater services in the linear '*take, make, waste'* approach (Diagger, 2009: 809; Mitchell, 2006: 589; Brown et al, 2008: 1, Gleick, 2000: 127; Sapkota et al, 2016: 155), and proposes "closing-the-loop" and managing the "complete" or "total" urban water cycle more holistically, in an integrated manner (Biswas, 1981: 181; Brown et al, 2011: 4043; Baker, 2009: 11; Hooper, 2003: 14; Öberg et al, 2014; Water by Design, 2010: iv; Wong et al, 2008: 2).

SUWM and integrated arguments emerge from a concern about resource constraints and the availability of future supplies (Daigger, 2009: 809). In Australia, there is a robust integrated water management practice: policy shifts in favor of "water sensitive cities" are triggered by frequent drought conditions (Brown et al, 2008; Wong et al, 2008: 2). Similarly, in Singapore, a global front runner in integrated water management, the incentive to wean the country from its historical dependence on Malaysia for water supplies gives rise to the *Four National Taps* strategy, which includes a range of measures targeting demand management, water use efficiency, waste curtailment, and water supply diversification (Bahri, 2012: 24-25).

The integrationist agenda gains traction from a series of global policy dialogues that align with sustainability. The 1991 World Water Council (WCC), the 1992 International Conference on Water and the Environment, and the 1997 UNESCO International Conference on Water, are significant global gatherings that mount an agenda for Integrated Water Resource Management (IWRM) (Grigg, 2014: 414). These global platforms promote the importance of sustainability in the water management discourse:

Integrated Water Resources Management is a process that promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (Global Water Partnership - Technical Advisory Committee (GWP-TAC), 2000).

Although there are already specific examples of practical design and planning experiments that demonstrate sustainability in practice – for example, *The Woodlands* and the various urban water reform pilot projects by US city utilities demonstrate the potential for multiple functions beyond the "conventional" services of water supply, sewerage and stormwater – the international policy normative calls for integration and sustainability challenge the dominant model of water delivery more visibly and signpost the shift in values globally.

These calls highlight a noticeable change in tone from the positive appraisals of the "Drinking Water Supply and Sanitation Decade" (1981–1990), which celebrate the success of multilaterals such as the World Health Organization (WHO) in improving potable water and sanitation access (Hering et al, 2013: 1082), towards warnings of a "global water crisis" (Cashman & Ashley, 2008: 8-11). Sustainability often appears in relation to concerns about supply in the face of "growing demand" from previously non-industrialized countries, and the challenge of meeting the aspirations of rapidly urbanizing populations with traditional water resources development (Cashman & Ashley, 2008: 10; Cosgrove & Rijsberman, 2000: 3; Mitchell, 2006: 590; Bahri, 2012: 2; Grigg, 2016: 716). In global water management discourses, sustainability is now most often in terms of the challenges of providing water effectively, efficiently and *equitably* (Cosgrove & Rijsberman, 2000: 3).

3.3.4 Green Infrastructure (GI) and the multifunctional appeal

Innovative design plays an evolutionary role, and a growing engagement with multiple function innovation is evident across disciplines, for example, in engineering and chemistry, the development of multifunctional materials such as CO^2-absorbing cement and asphalt is the result of initiatives to use materials strategies to reduce resource consumption (Anastas & Zimmerman, 2013). Similarly, in architecture, experiments with multifunctional buildings aim to combine several uses, such as educational, recreational, residential and commercial, in one specific space (BDG, 2012).

Along with demonstrative experiments and practical applications, both practitioners and theorists in various fields dealing with the physical environment, including landscape architecture, environmental planning and other applications that could be considered "sub-disciplines" of ecology (Johnson & Hill, 2002: 1; Hill & Larsen, 2013: 215), are making a concerted effort to refine and articulate the definition of "multifunctional" infrastructure.

One of the most active articulations of multifunctional infrastructure comes from proponents of "Green Infrastructure" (GI), or the use of vegetative systems to deliver ecosystem functions. The idea of multiple benefits is central to GI, which is a paradigm shift away from, and a deliberate contrast to, "grey" infrastructure, which typically addresses only specific goals (Fletcher et al, 2014: 8; Matthews et al, 2015: 157; Kambites & Owen, 2006: 486; Ahern, 2007: 247).

A movement from American landscape planning uses GI as a strategic landscape approach for urban and regional planning (Benedict & McMahon, 2002: 12; Ahern, 2007). The rapidly growing discourse on GI reframes previous ideas, such as the aesthetic and luxury of parks and greenways, as well as more specific site-design strategies, such as natural drainage (Walmsley, 2006: 257; EPA, 2017). While several commentators view GI as a repackaging of earlier ideas, the association of the green or ecological specifically with infrastructure is a cultural observation important to the ecological turn (Steiner et al, 2013: 258). Benedict & McMahon's *Green Infrastructure: Smart conservation for the 21st century* (2002), calls for a shift beyond conventional environmental protection and conservation and ambitiously redefines ecosystem and landscape elements as part of the infrastructure that serves society:

> Green infrastructure is the interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations provide ecological, social and economic functions to humans (Benedict & McMahon, 2002: 12).

Benedict and McMahon use the term “infrastructure” to shift perspectives away from green or open spaces as luxury items, and positions them instead as central to a nation’s “life support system” (2002: 5). Their work is an extension of the regional greenway movement, and attempts to give the concept of greenways contemporary relevance amid current sustainability challenges (Benedict & McMahon, 2002: 13-15; Walmsley, 1995; Kambites & Owen, 2006; Ahern, 2007; Mell, 2009; Fishman, 2011; Ahern, 1991, 1995). The progression towards GI as a synonym for interconnected greenways and ecological networks is evident across a range of theory and practice since the 1990s (Ahern, 1995: 132; Walmsley, 2006: 257; Allen, 2012: 17; The Conservation Fund, 2004). In the UK, Kambites and Owen define the central precept of GI as the “connected network of multifunctional, predominately unbuilt, space that supports both ecological and social activities and processes” (2006: 483). An early example of GI planning is the 1994 Florida Greenways Commission, which sets out to elevate the societal value and functions of natural lands to the same level of importance as grey infrastructure:

> The Commission’s vision for Florida represents a new way of looking at conservation, an approach that emphasizes the interconnectedness of both our natural systems and our common goals and recognizes that the state’s ‘green infrastructure’ is just as important to conserve and manage as our built infrastructure (The Conservation Fund, 2004: 1).

Rather than being concerned with amenity, Thomas and Littlewood (2010: 210) challenge the analogy of hard infrastructure with essential city development, and thus distinguish their concept of GI from other and earlier notions of green belts and corridors. Recently, GI has come to be regarded as a hybrid of built infrastructure and human-made ecosystems, such as stormwater wetlands for urban drainage or bicycle corridors that provide habitat functions (Ahern, 2013: 1208). The American Planning Association (APA)’s publication *Green Infrastructure: A Landscape Approach* (2013), explores how the concept GI has expanded in the lexicon of planners and designers beyond notions of “protection” or “conservation” (Rouse & Bunster-Ossa, 2013: 1):

> Taken broadly to mean a network of spaces, places and design elements – natural or constructed, public or private, local or regional – that provides such benefits, landscape looms large as a catalyst to achieving sustainable futures for cities and regions (Rouse & Bunster-Ossa, 2013: 3).

GI consequently attracts a much wider range of scholarship than does greenway planning. Its ideological orientation is a useful practical counter to the negative history of, “grey” infrastructure (Finewood, 2016). An illustrative example is the call by Schilling and

Logan for "greening the rust belt" in America, and replacing vacant areas in shrinking cities with green infrastructure to address urban blight and abandonment (2008: 453). In its application to stormwater, GI has conceptual as well as practical roots in natural drainage pilots that use vegetative or "soft" strategies, such as green roofs, bio-swales, porous surfaces, rain gardens, vegetative median strips, and rainwater harvesting, for natural hydrological principles (Hoang et & Fenner, 2016: 739). The US Environmental Protection Agency (EPA) regards GI as a suitable wet weather strategy for managing stormwater runoff, reducing sewer outflows and improving water quality, in contrast to single-purpose grey infrastructure that does little more than move stormwater away from the built environment (EPA, 2008). GI stormwater designs therefore become replacements for conventional grey infrastructure systems in providing urban ecological services and functions (Wickham et al, 2010: 186-187; Rouse & Bunster-Ossa, 2013: 10).

GI sometimes supplants or appears synonymously with other concepts such as LID (Fletcher et al, 2014). There are versions of WSUDs, SUDs and LIDs in the US, the UK, as well as in Australia, that follow natural hydrological processes and that often include, or are simultaneously, GI (Hoang & Fenner, 2016: 740; Keeley, 2013).

The definitional debates surrounding GI are extensive. An impressive literature exists on the challenges relating to its definitional ambiguity, value contestations, planning relevance, and "institutional schizophrenia" (Allen, 2012; Davies et al, 2006; Matthews et al, 2015: 157; Mell, 2013; Roe & Mell, 2013: 659; Madureira & Andresen, 2014; Wright, 2011). GI suffers from significant "definition creep", especially within the realm of renewable energy (Allen, 2012: 19), and is sometimes regarded as synonymous with the greening of grey systems, such as energy retrofits. Hannah Wright is especially skeptical of GI's momentum, arguing that attempts to capitalize on the new concept often result in ambiguous ideas without authentic practice (2011: 1003). Another critical perspective regards the slow uptake of GI as reflecting confusion, and considers it to have the potential for interfering in existing green space planning efforts (Matthews et al, 2015: 157). Some practitioners grapple with GI's conceptual debates to contribute to planning practice. The *Green Infrastructure Planning Guide* (Davies et al, 2006) engages with the history and contexts of GI to assist with "on the ground" initiatives within the spatial planning process.

A South African project for the City of Johannesburg (CoJ) by Schäffler and Swilling (2013) spans visual, spatial, institutional and economic analysis is an attempt to understand GI and provide policy-relevant data to assist with infrastructure delivery. This project is the third iteration of a GI service delivery strategy. The initial report, the *State of Green Infrastructure for the Gauteng City-Region* (GCRO, 2018) reveals how redefining infrastructure offers academic planners in South Africa an opportunity not only for conceptual innovation, but also for addressing some of the major issues associated with service delivery. As Schäffler and Swilling reflect:

> This is not a state of the environment report focusing on the issues of 'conservation' of 'nature'. Rather it is designed to extend our understanding of what we define as 'infrastructure' and thereby open a critical engagement with the relationship between conventional service networks and vegetated dimensions of the urban landscape (Schäffler & Swilling, 2013: 5).

In this context, green infrastructure is intended to:

> address critical infrastructure backlogs in development pressure points, especially in tight fiscal circumstances where it simply would not be feasible to build overlapping 'hard' infrastructure networks for various services (Schäffler & Swilling, 2013: 12).

While the semantic and institutional debates are important, the attraction of GI in tandem with the term "infrastructure" yields a fundamental insight about function. Specifically, rethinking infrastructure provides the opportunity of achieving multiple functions or purposes. The greenways movement is active in driving a shift in terminology during the 1990s towards greenways as addressing "multipurpose" demands, beyond conservation, growth management and regional spatial planning (Ahern, 1995: 132; Benedict & McMahon, 2002:14; Kambites & Owen, 2006; Mell, 2010). This is evident in the work of landscape ecologists and environmental planners arguing for a reinvention of green space planning as GI, using "multifunctional landscape frameworks" (Lovell et al, 2013: 1448), for contexts with intersecting infrastructural, climatic and ecological challenges (Götz & Schäffler, 2015). The emergence of the term "multifunctional" infrastructure, which finds a particular articulation in current GI discourse as well as its earlier iterations such as greenway planning and natural drainage practices, reflects a theoretical response to overcoming intersecting sustainability issues (Haines-Young & Potschin, 2000: 112).

One of the early articulations of multifunctional ideas comes from American greenway planner, Jack Ahern:

> Greenways are networks of land containing linear elements that are planned, designed and managed for multiple purposes including ecological, recreational, cultural, aesthetic, or other purposes compatible with the concept of sustainable land use (Ahern, 1995: 134).

The idea that ecological functions provide humans with multiple benefits, and are therefore as deserving of attention as "traditional" infrastructure services, becomes a key argument for the greenway movement in its progression towards GI (Hagan, 2015;

Sandström, 2002; Jim & Chen, 2003; Tzoulas et al, 2007). The reorientation to multipurpose and onwards to multifunctional planning reflects relevant contemporary issues and agendas at the Rio Summit of 1992, which highlights issues within "traditional" conservation and natural resources debates that are inherent to greenway planning (Ahern, 1995: 132; Kambites & Owen, 2006: 484; Sandström, 2002: 374).

Greenway proponents such as Jack Ahern have ideological roots in ecology and its sub-disciplines, such as landscape ecology, that emerge following the McHargian era and that influence spatial or physical views of landscape functions. Ahern views landscape fragmentation as a weakness of the McHargian philosophy, and, instead, his focus is on understanding the different spatial combinations and compatibilities of different land uses through the study of pattern and process (Ahern, 2013: 1203; Ahern, 1995: 132; Forman & Godron, 1986: 313; Johnson & Hill, 2002: 4). Several subsequent scientific and methodological endeavors to map and represent physical connectivity, corridors and compatibility of multiple land uses, derive from landscape ecology (Ahern, 1995: 134, 2003: 111; Flink & Searns, 1993; Hall, 1991; Forman, 2008: 1, 7; Forman & Godron, 1986: 398; Lovell & Johnston, 2009: 213, 2013: 1448; Johnson & Hill, 2002: 1-11; Steiner et al, 2013: 356; Sandström, 2002).

In another example from landscape ecology, in the *Ecology of Greenways* (1993), Smith and Hellmund apply decision tools for emphasizing the spatial and the temporal interactions within ecosystems (see also Hellmund & Smith, 2006: 44). The work by Flink, Olka and Searns in their "multi-use" trail model for addressing environmental degradation, transport and social challenges is also relevant (2001: 34; see also Flink & Searns, 1993). In Donna Hall's view, also influenced by landscape ecology, the physical view of multifunctionality is an attempt at "synthesiz[ing] humans into a functional landscape approach" and part of the wider shift towards functionalism in landscape discourse, and towards biological and cultural diversity, specifically (1991: 16).

There are important reasons for this shift, such as the contentious ecological and social history of greenway planning in the US, where aesthetics sometimes trades off biodiversity goals, with white, suburban groups generally enjoying greater access, (Talen, 1998, 2010; Lindsey et al, 2001; Pincetl, 2007; Wolch et al, 2014: 235-241; Gobster, 1995, 2002; Nassauer & Opdam, 2008: 633-634).

The popularity of a focus on ecosystem services is evident in the burgeoning cross-fertilization between ecology, economics, and planning and design disciplines, which, together, make a case for investing in multiple ecosystem benefits as infrastructure services (Bolund & Hunhammar, 1999; Lovell & Taylor, 2013). In addition to spatial and physical interpretations, the multiple functions of landscapes are commonly considered alongside “ecosystem services”, or the functions or benefits that ecosystems provide (Constanza et al, 1997). The ecosystem services concept forms a key part of GI discourse in motivating for investment in the multiple benefits of vegetated systems, as well as in the more recent articulations of multifunctional infrastructure (Culwick et al, 2016: 8; Steiner et al, 2013: 357). Beyond the academic and policy discourses on “green growth and sustainability transitions” (Bobbins & Culwick, 2015: 32), and outside of the realm of more purist ecology, scholarship from South Africa illustrates the appeal of the concept of ecosystem services for redefining GI as multifunctional for improved service delivery in a challenging infrastructure environment (Schäffler & Swilling, 2013; GCRO, 2018). Bobbins and Culwick use the ecosystem services concept to frame GI as a planning approach incorporating the services of “natural urban assets, such as trees, parks, planted roadside verges, and other ecosystems into the everyday planning of cities” (2015: 32). Environmental planners in South Africa regard GI as an “innovative planning approach for urban infrastructure and services” that hinges on valuing “green assets” and ecosystem services on a par with everyday “grey” infrastructure and services, such as electricity lines or roads and transport (Schäffler & Swilling, 2013; Bobbins & Culwick, 2015: 32). This work typically involves quantitative valuations of ecosystem services and reflects the influence of the 2005 Millennium Ecosystem Assessment (MEA) on ecosystem science (Alberti, 2010; MEA, 2005).

The popularity of GI and its multifunctional applications is therefore an important trend within the ecological turn that simultaneously reflects a semantic reframing of previous ideas and an attempt at theoretical evolution, while maintaining contemporary relevance. The concept of multifunctionality that merges with noticeable momentum from landscape discourse reflects a fundamental re-articulation of human value systems. Haines-Young and Potschin propose a “model” of multifunctional landscapes that are not simply the co-existence of nature and societies, but the human constructions thereof (2000: 110). This recursive understanding of multifunctional ideas provokes an important question about how practitioners understand and evaluate the shift towards multiple infrastructure functions. This is taken up in greater detail in the next chapter.

3.4 Conclusions

The historical trajectory in this chapter demonstrates that the three basic functions of urban water infrastructure – water supply, sewerage and stormwater services – are shaped by legislative changes, social ideas, and cultural movements. From mid-century, “the environment” becomes a popular cause and eventually a government mandate. Innovative designs and practical, “on the ground” pilot projects differ from efforts that refine concepts theoretically, or through design competitions and proposals (Steiner et al 2013: 536), and challenge existing conceptions about infrastructure. In the 1970s, environmentalist narratives consider philosophies of infrastructure development more broadly – in relation to the "self", to other people, and to nonhumans (Stern & Dietz, 1994: 66). Social learning also happens through direct experience – ideological and normative proposals for sustainability indicate a value shift in terms of human abilities to govern and learn from previous actions (Dietz, 2013: 14081).

Pilot projects play an important role in overturning prevailing ideas about infrastructure function by demonstrating the multiple possible benefits of alternative strategies. Experiments such as *The Woodlands* and other city pilot projects indicate infrastructure value shifts, evolve concepts, develop methods of monitoring and evaluating new ideas, and offer a practical platform for learning and producing knowledge about sustainability.

Kelly Shannon reflects that a combination of functional, utilitarian and symbolic uses mounts a shift towards "soft" engineering working with forces of nature (2013: 1664). She notes that the shifting functional context for urban water infrastructure is "[a] cocktail of nostalgia and ecological concerns that often results [for example,] in the transformation of post-industrial harbor and riverfront sites into commercially successful leisure playgrounds", and city developments that "juxtapose landscape, infrastructure and urbanization" (Shannon, 2013; 165).

This chapter analyses the negative role that urban water infrastructure has played in the environmental histories of cities and what lies beyond the cocktail of nostalgia and ecological concerns that try to do it differently. While the idea of multiple functions is not new, this chapter shows that a lively body of theory and practice is reframing infrastructure as multifunctional. There are important contributions to reframing infrastructure from scholars and practitioners in various disciplines concerned with the physical environment, which span a broad spectrum of theory, methodological advances and practical experiments (Johnson et al, 2002: 1; Turner, 1989: 171; Pickett et al, 2004: 369; Alberti, 2010: 180; Hall, 1991: 14). Susan Herrington reflects that modern landscape architecture develops out of understanding landscape function in terms of ecological processes (Herrington, 2016: 35-36). Designers and planners play a "mediating role" between the built environment and ecological function, and so contribute to the ecological turn in urban planning and design (Mozingo, 1997: 47).

Other fields, such as chemistry and engineering, also evidence multifunctional practices, but the reframing of infrastructure as multifunctional has a particular voice in landscape discourse stemming from landscape ecology, urban and environmental planning, and greenway planning, in particular. The idea of multifunctional infrastructure is especially evident in relation to landscape innovations such as bio-swales or "green" roofs, and contributes to the argument for multiple landscape or ecosystem benefits (Steiner et al, 2013: 359). GI offers an accessible and convenient discourse for this reframing and reflects the attempt by scholars and planners to retain strategic relevance (Lovell & Taylor, 2013: 1448; Steiner et al, 2013: 359; Meerow & Newell, 2017; Otte et al, 2007: 640).

Under the influence of ecology and its sub-disciplines, multifunctional ideas often emerge as physical concepts and as ecological principles or qualities of landscapes (Haines-Young & Potschin, 2000: 112). There is also a strong support base, and cross-fertilization, from economic perspectives about ecosystem function that is influential in how GI becomes multifunctional and sustainable (Bobbins & Culwick, 2015: 8). The attraction to multifunctional ideas is part of a general vision of integrating ecological and social functions in urban landscapes, which, from a cultural perspective, reflects positively on humans' valuing of the physical environment. This provokes the question of how we perceive multifunctionality and understand, engage, design for, and evaluate function, beyond its theoretical constructs.

PART 2: INFRASTRUCTURE PRACTICE AS NEW KNOWLEDGE

Chapter 4. Infrastructure as a cultural topic

> People commonly envision infrastructure as a system of substrates, railroad lines, pipes and plumping, electrical power plants, and wires. It is by definition invisible, part of the background for other kinds of work. It is read-to-hand. This image holds up well and for many purposes – turn on the faucet for a drink of water and you use a vast infrastructure of plumping and water regulation without usually thinking much about it (Star, 1999: 380)

4.1 Introduction

The chapter begins by reflecting on infrastructure as ethnography and considers Susan Leigh Star's contribution in this regard. It then shows how studying the methods and tools of infrastructure practices aids our understanding of collective values and narratives. Refining Star's portfolio of "tricks", the chapter contributes an ethnomethodology of infrastructure practice that foregrounds the everyday, often mundane, practices of municipal engineers, planners and consultants. This draws on Harold Garfinkel's ethnomethodology of "people's methods" for infrastructure practices as knowledge about how infrastructure actually happens (1967). The chapter then suggests a service delivery interface for understanding the tools, rationalities and language's behind infrastructure practices (Miller, 1994: 286; Foucault, 2010: 115; Weick, 1995: 3-4).

Engaging history and previous attempts to integrate social and ecological function is an essential step towards a more mature, sustainable meeting of planning and design. Donna Hall's cynicism about previous struggles to provide relevant ecological function in society is a clarion call for improving the use of functional ideas about landscapes (1991: 18). In contrast to conceptual ideologies and theoretical abstractions, the historical trajectory of urban water infrastructure illustrates the specific role of innovative design in including, as well as mimicking, ecological functions for performing key urban functions, such as water supply or drainage (Hough, 2004: 1; Johnson & Hill, 2002: 2; Hill, 2009: 146. 163; Herrington, 2016: 33; Scott et al, 2016: 69).

Earlier references to multi-functional, multi-purpose and multi-use landscapes by McHarg (1969), Whiston Spirn (1988), Lyle (1994), Thayer (1994), Hough (1995), and Strang (1996), among others, show the ecological turn straddles a continuum of conceptual and normative engagements. The previous chapter demonstrates that, while contentious, and subject to its own need for reinvention, the ecological turn in urban planning reflects an interest by both theorists and planners in integrating ecological and social function. The traditions of applied design and physical environment planning disciplines are significant in driving the turn toward integrating ecological function at an urban scale. Design ideologies, such as Landscape Urbanism*,* draw on multifunctional concepts in analytical attempts at redefining as landscape and infrastructure (Nijhuis & Jauslin, 2015; Waldheim, 2006; Thompson, 2012).

Physical environment traditions show that in addition to something spatial, functional views of landscapes, "green" or "ecological" infrastructure (Steiner et al, 2013), are also social constructions. The ascendance of GI highlights how a continuum of values about the biophysical world is a reflection and extension of people's concerns about the fate of their communities and living environments (Bergeron et al, 2014: 109). It is helpful to appreciate the creation of functional concepts as something inherently cultural, deriving from the landscape user's and stakeholder's own perspectives (Otte et al, 2007: 639-640; Potschin & Haines-Young, 2011). Cultural geography, the human shaping of landscapes (Bergeron et al, 2014: 109), first gains traction in the 1930s, particularly in North America, and later through movements of critical regionalism emphasizing identity in the landscape, through landscape perception and individual psychological enquiries (Egoz, 2013: 273).[10]

Multifunctional landscapes require an engagement with how human value systems successively or recursively re-define what is important in terms of the ecological (Haines-Young & Potschin, 2000: 112). Antrop elaborates that the values humans assign to land depend on utility and functionality, the references for which are constantly changing (2006: 166). This cultural view of function is especially relevant in light of the shifts in planning and design discourse towards articulating "infrastructure" as a concept for synthesizing ecological and social function (Hill, 2009; Little, 2005; Steiner et al, 2013). Haines-Young and Potschin (2000: 122) offer a practical consideration of value assignments:

> If we are to understand and plan multifunctional landscapes, then we must also examine the multiple and often conflicting values that people assign to the resources that are associated with them (Haines-Young & Potschin, 2000: 122).

The assumption that new conceptualizations can redefine the functions of infrastructure

[10] The early history of positivist planning in the US is a particular driver of postmodernism's emphasis on culturally situating the physical design and social designer as both culturally situated and constructed (Weller, 2001: 6).

and resolve sustainability (Haines-Young & Potschin, 2000: 111) should not, however, be taken at face value. For instance, attachments of meaning to the biophysical world vary significantly (Bergeron et al, 2014; Antrop, 2000) and the different adjectives humans assign do not, in fact, necessarily represent new perspectives on function. Discontent with the Landscape Urbanism paradigm, in terms of its acceptance of lower density for the purposes of protecting "natural" areas, reflects the challenge of associating different ideas about function (Duany, 2013; Hill & Larsen, 2013: 22). Prescriptions for ecological integrity, such as Forman's four principles,[11] while valuable in theory, often exclude the applicability of GI to contexts of major landscape alterations: there may be several types of GI, such as school grounds, urban farms and recreational parks, which may not be biologically diverse, yet still provide valuable social and economic functions for local communities.

Research emanating from GCRO in South Africa is illuminating within efforts to quantify GI and redefine infrastructure as multifunctional. This research set out to represent interconnectivity of "green assets" and identify ecosystem hubs and links, using a McHargian overlay (Schäffler, 2013: 23).[12] The GCRO's experience with GI as a decision-making application reflects the complexities of uncovering social-ecological interactions, which create uncertainties for planners in understanding multiple functions (Lovell & Taylor, 2013: 1459). Much of the work faced recurring data challenges, such as the positional and attribute inaccuracies that result from poor data lineage, insufficient logical consistency and lack of completeness in public records (Schäffler et al, 2013: 23).[13] Data errors and uncertainties prompted the establishment of a *Green Infrastructure CityLab* to facilitate the co-production of policy-relevant knowledge in Gauteng by government practitioners and researchers (GCRO, 2014). The *CityLab* is an attempt to integrate GI into infrastructure planning processes through "green asset data collection and mapping, methods of valuing green assets, and design options for green asset alternatives to conventional grey infrastructure approaches" (GCRO, 2014).

From a cultural perspective, GI and the articulation of multifunctional ideas contain important insights about collective assignments of meaning to, or narratives about, the biophysical world. While there are critical perspectives that caution against "environmentalism" as a broad-based concern due to particular value systems or cultural

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[11] Forman's four principles are: (1) natural levels of plant (primary) productivity; (2) high levels of native biological diversity; (3) natural (low) rates of soil erosion and nutrient loss; and (4) clean water and healthy aquatic communities (Thorne, 1993: 24).

[12] The overlay method uses vector layers associated with the particular geographic and/or historical context of the study area.

[13] Positional accuracy gauges how well the location, size and shape of the real world translates into GIS data, and attribute accuracy reflects how well tabular characteristics represent reality (Bolstad & Smith, 1992). Data lineage, logical consistency, completeness and currency refer to inaccuracies that can be incorporated into the datasets through determining the data source, the faithfulness of the dataset and topological errors.

positions (Meyer, 2000), movements such as GI and articulations of related ideas are relevant to tracking the extent of value shifts towards infrastructure. Methods such as GI decision-making applications have the potential for influencing the design and planning of our physical environments. Tracking these unfolding forms of knowledge highlights the importance of the methods planners use for understanding the shifts in theory and practice.

4.2 A provocation: value shifts?

Multifunctional ideas reflect a conceptual evolution. Given that various communities of scholars and practitioners are promoting the idea of multifunctionality, the strategic question arises about how urban governments understand, examine assess and internalize multiple functions. What methods do urban governments have at their disposal for examining multifunctional infrastructure? The focus of this chapter is initially an enquiry into the concepts, methods and techniques for communicating and evaluating multiple functions, in an attempt to make sense of the ongoing shifts in theory and practice towards multifunctional infrastructure. This lays the foundation for presenting a provocation for developing a cultural approach to infrastructure and utilizing ethnomethodology as a research method.

Scholars of infrastructure as a cultural topic are part of a lineage of thinking about the world of appearances, human self-awareness and consciousness, but cultural approaches to infrastructure represent one of the major philosophical shifts in human perception of nature. The phenomenology emanates from Kant's Copernican turn, which sets in motion the sociological study of how humans perceive the physical world and struggle to formulate an all-encompassing "physical" definition of nature (Marx, 2000). Branches of axiology, such as aesthetics and ethics, consider how to value the physical world in terms of priorities or preferences (Callicott, 2013), and the human–nature relationship also attracts sociological extensions of cultural geography and variants of environmental ethics. Cultural approaches to infrastructure that apply constructivist theories to the physical environment view infrastructure specifically as a representation of social values (Coulon, 1995: 16; Cosgrove & Daniels, 1988).

White (1967) traces the roots of modern ecological thought as a function of how humans create and change their environments and argues that a particular conceptual shift takes place during the industrial revolution in terms of the development of scientific hypotheses and technologies that affect humankind's relationship with, and exploitation of, the environment. Ethnographers take the view that it is important to foreground the everyday, often mundane work or practices that exist behind infrastructure, and reveal taken-forgranted dynamics about social patterns, functions or values. Scholars studying "technopolitics" build on Foucault's idea of governmentality, which reflects the political rationalities of technological projects or decisions (Foucault, 2010: 70). Anita von Schnitzler (2016, 2010, 2008) and Timothy Mitchell (2002) examine infrastructure ethnographically in terms of the underlying systems, rationalities and work processes. Some anthropologists adapt Hughes's history of technology, which examines society's intentions, use and definitions of large technological systems (Hughes, 1987: 80).

4.3 Infrastructure as ethnography

Langdon Winner's *Do Artifacts have Politics?* (1980) sets in motion a vibrant body of research on the social determination of technology that questions how social and economic systems embed forms of technology, affecting power dynamics and experiences of citizenship (1980: 122-123).[14] Infrastructure as ethnography takes cues from cultural geography in also viewing physical forms as evocative of time and place (Glacken, 1969; Mozingo, 1997: 50; Thayer, 1994: 13; Meyer, 2008: 243). The field of Technology and Society Studies (TSS) similarly exhibits interest in the social determination of technical systems, concerning the construction of artifacts, systems and design by society (Lievrow & Livingstone, 2009; Evans et al, 1999).

Infrastructure thinking attracts ethnographic perspectives that seek out the relational properties of physical or technical systems (Star, 1999: 380). In *The Ethnography of Infrastructure* (1999), Star uses the term "invisible work" to refer to the details of work processes behind large-scale infrastructure systems that reveal narratives, such as service delivery, and relational values, such as divergent access to water services (1999: 380). Star uses infrastructure as a prompt for studying seemingly boring objects from an ethnographic perspective and examining the narratives, work and functions underlying large-scale technical systems (Star, 1999). Star echoes Winner's appeal for highly qualitative methods, and recommends a trio of "tricks" to "unfreeze" and read the narratives, methods and practices that give infrastructure its relational ethnographic character (1999: 384):

> **Identifying master narrative and "others":** the narrative in information system speaks unconsciously from a presumed center of things, encoding into infrastructure a particular history.

[14] Winner cautions that reducing all technological artefacts to social forces risks overlooking technological phenomena as things in their own right. For Winner, the "politics" of physical artefacts include power and authority, as well as the activities that take place in artefact arrangements (1980: 123).

> **Surfacing invisible work:** information systems encode and embed work that is often not visible and needs to be articulated.
>
> **Understanding the paradoxes of infrastructure:** only by describing both the production and hidden task of articulation, together and recursively, can we understand why some systems work and others do not.

As an example of what the full extent of Star's tricks might encompass, Brian Larkin considers the technical function of a road as "[transporting] vehicles from one place to another, promoting movement and realizing the enlightenment goal of society and economy as a space of unimpeded circulation (2013: 332). However, a road can also be an excessive fantastic object that generates desire and awe in the autonomy of its technical function (Larkin, 2013: 332). In many African states, infrastructure objects – roads, factories, bridges – ostensibly have a technical function, yet in practice, they sometimes operate as a conduit for government contracts and patron–client reward networks (Larkin, 2013: 334; Mbembe, 2001). In Asia, airports, high-speed rail and subway systems, and grand luxury commercial and residential architectural projects, represent "prestige infrastructures", yet all too often they exclude local populations (Howe et al, 2015: 5).

The Marxist and radical geography stance on the politics of infrastructure is beneficial in foregrounding social disparities and issues of access that manifest in service delivery. Star has a deep history of feminist research practices and consciousness-raising utilizing ethnographic fieldwork to read the "invisible layers of control and access" (Star, 2002) within material structures:

> [W]hen one begins to investigate the large-scale technical systems in the making, or to examine the situations of those who are not served by a particular infrastructure. … One person's infrastructure is another's topic, or difficulty (Star, 1999: 380).

Winner, Star, and other cultural geographers, grapple with individual and collective realms of infrastructure as analytical territories. Infrastructure represents both individual sites of experience, where access and control manifest, and collective formations of space that emerge through institutional policies, planning and processes (Cosgrove, 2003: 15). Cultural perspectives can therefore be useful in considering urban infrastructure as narratives of how urban governments provide sustainably for the future of their citizens: for instance, in highlighting discrepancies between how urban infrastructure management expresses socially desirable goals and how the outcomes from institutional arrangements actually emerge.

The challenge for cultural research, however, is that direct field exercises, with individuals or focus groups, may involve highly exploratory studies of the "micro" in particular spaces that are often too narrow, or are too distant relations of infrastructure decision-making (Jauhiainen, 2003: 397). Dourish and Bell propose that studying infrastructure from a cultural perspective therefore requires two analytical registers: The first is a socio-political reading of infrastructure as a crystallization of relations such as power and access (2007: 416). The second is an experiential reading of infrastructure, which focuses not so much on the ways in which infrastructure reflects institutional relationships, but more on how they shape individual actions and experience (Dourish & Bell, 2007: 417). Mediating between these two analytical levels contributes an important perspective about the influence of the "day to day", or tangible aspects of infrastructure such as routine management meetings, on service delivery outcomes.

Von Schnitzler's analysis of the political life of prepaid water meters in South Africa is an example of reading infrastructure through broader socio-political stories together with everyday accounts of technologies from practitioners' perspectives. She reveals how different political and engineering narratives produce distinct ways of "coding" or framing water technology. The contentious and highly discriminatory prepaid system is affected not only by technical processes and functions, but also by social factors such as political conceptions, ethical values and institutional relations (Von Schnitzler, 2008, 2010).

Von Schnitzler's work is arguably more expansive than Star's ethnography in connecting Marxist critical geography to the specific life of an urban water infrastructure strategy. She engages with the industry of government officials, engineers and users to narrate the journey of prepaid water meters from political conception and organization to technical functions in design and implementation (2008). Taking infrastructure practitioners' own knowledge as the object of analysis reveals the discursive, managerial and professional forms of making infrastructure happen (Walby, 2007: 1011-1012; May, 2002; 4). Von Schnitzler's analysis also echoes Dorothy E. Smith's original institutional ethnography and approach of "text work" that analyzes practices of inscription, such as reading, interpreting and writing, from an institutionally derived hermeneutic frame, which actively produces the "truth" of an event (Smith, 2001, 2005).

The focus on the actual work in producing infrastructure is also indicative of Garfinkel's "ethnomethodology", which is not a method per se, but a "common sense" reasoning that contextualizes and situates analysis in a documentary style (Button et al, 2015). In this formulation, *ethno* refers to members of a social group, and *method* to the process of practical action and practical reasoning – the things people continually do – to create and recreate recognizable social order (Rawls, 2008: 701, 2011: 90-91). Ethnomethodology therefore looks to uncover how society puts something together, how to do it, and how it gets done; in effect the social structures of everyday activities (Garfinkel, 1967, 1991: 371).

The major caveat to ethnomethodology, or the "study of methods", is the absence of its own formal methodology (Atkinson, 1988: 455; Rawls, 2011: 99). Garfinkel is critical of ethnomethodology as overly jargonistic and provokes debate about the contribution of theory, as well as about whether studying local orders or details does, in fact, represent actual social dynamics (Emirbayer & Maynard, 2011: 225; Rawls, 2011: 119). Anne Rawls defends Garfinkel's critique of allowing theory to define research questions in conventional research that pursue agendas with a priori conclusions, which thereby miss the actual "lived" problem of order (2008: 709).

The growing field of decision-making studies and organizational theory reflects the more general interest in decision processes from the perspective of social learning (Kochenderger, 2015; Weick, 1995). Weick's notion of "sensemaking", as a way of understanding how human actors create as well as understand their realities, also features in ethnomethodology's approach of tracing the everyday activities or real-world order work to find out the logic of organizations (Bukh & Kjaergaard, 2012: 97; Crabtree et al, 2000b: 4; Weick, 1995: 10). Much of Weick's early work takes inspiration from Garfinkel's studies of decision-making processes in the 1960s and finds a voice in later work explicating what the members of organizations do in their common social practices (Bukh & Kjaergaard, 2012 97; Crabtree et al, 2000a; Weick, 1995: 10l).

It is useful to reflect on how applications of ethnomethodology trace patterns, or reveal what happens in practice, and reflect Weick's theory of sense-making in organizations (Weick, 1995). Information and design technology disciplines analyze the method in computer and virtual technologies for understanding the processes of social learning and reasoning with the view to informing system design processes (Dourish & Button, 1998; Crabtree, 2000a, 2000b). Similar research by Rhinesmith contributes to viewing infrastructure such as cloud computing as a theoretical framework for understanding how software projects work in different political, economic, historical and cultural contexts (2010: 2). Work from Bukh and Kjaergaard (2012), stemming from public management and accounting disciplines, analyses the Danish utility sector using empirical accounts and descriptions of what utility actors do and how practitioners in an individual utility, as a community of members, create and maintain social order.

While not a specific method for research, ethnomethodology is valuable as a specific entry-point into the study of infrastructure. The applications in information technology and infrastructure utilities illustrate how researchers study practitioner methods as knowledge about rationalities and system function (Crabtree et al, 2000a; Rawls, 2008: 717; Greenberg, 2010: 21). Reflecting on their research into virtual technologies, Crabtree and colleagues note that understanding how members in a society experience and conduct their everyday affairs is part of a practical approach specifically because of the focus on the ordinary and mundane (2000a). In light of the widespread use of electronic devices and software, it is easy to see why a great deal of information and virtual technology research makes use of ethnomethodology. There are useful analogies and insights from these other fields for examining infrastructure planning methods, such as spatial decision-making, economic valuation or asset management, which are often behind-the-scenes to the proverbial "pipe".

4.3.1 Unfreezing infrastructure

This section examines how Star's suggestions might assist in studying methods of practice and understanding the rationalities, values and functions behind urban infrastructure. According to Star, reading infrastructure ethnographically requires the kind of substantial deep reading (which she terms "unfreezing") that brings an ethnographic sensibility to infrastructure data (1999: 384). She regards the process of unfreezing as being constituted by common fieldwork methods, such as literary and historical analysis, interviews and observations, systems analysis and usability studies (Star, 1999: 384). As mentioned earlier, she suggests three "tricks" for unfreezing the values that underlie particular infrastructure practices:

1. Identifying master narrative and "others"

> [T]he narrative in information system speaks unconsciously from a presumed center of things, encoding into infrastructure a particular history (Star, 1999a: 386).

Star calls for a deconstructive reading of infrastructure that reveals the presence of assumed ideas, or master narratives, which represent the "unconscious center, the pseudo-inclusive generic" (2002: 119), for example, records that encode only heterosexuality, gender binaries or racial classifications, and fail to reflect diversity (Star, 2002: 119). Star's narrative identification approach is essentially about studying the systems of classification, a process that implies "digging" into the settings and decisions to invest in particular options, which physical or technological infrastructure then in turn encodes or inscribes (Star, 2002: 199).

Star's critical reflection of master narratives stems from her feminist geography roots and is useful for unearthing the narratives that present in urban infrastructure strategies and visions. For example, politicians, non-governmental organizations, civil society and academics, often rally "service delivery" to make statements about enhancing access to infrastructure services, with the broader goals of political promotion (Pieterse, 2005: 40). A case in point is the Water Demand Management (WDM) strategy of the municipal entity Johannesburg Water (JW) in South Africa. A statement on the City's website reflects a dual narrative about resource conservation and poverty reduction:

> There is growing realization that the water resources are under severe threat and a concerted effort needs to be made if resources are going to be preserved for the future. The City of Johannesburg recognizes water as key to winning the battle against poverty and that its scarcity could be a limiting factor to economic growth (CoJ, 2011).

In addition to sustainable resource use for poverty reduction, another key institutional incentive is cost-effectiveness, which often presents as an efficiency narrative in terms of wastage and operating efficiencies (JW, 2011: 18). Revealingly, the City also states that the WDM strategy is different to "one that would seek to reduce the water demand of middle to high income consumers and thus negatively impact on the ability of the city to generate revenue through the sale of water" (JW, 2011: 18). For instance, JW views the use of tariff increases to curb consumption as a potential threat to the City's financial sustainability (2015: 49).

Analyzing the WDM strategy is therefore useful in foregrounding the narratives that JW presents to the public, and discovering the underlying narratives, such as "unaccounted for water", which affect infrastructure decisions and investment (Box 1).

5.2 Key Programmes and Projects

5.2.1 Water-Demand Management Programme

WC-WDM is one of JW's key flagship programmes, which aims to reduce the levels of water losses. JW is migrating from the water-losses methodology of UFW to using the-internationally recognised methodology which is NRW – as defined by the IWA. The rationale of the methodology is explained below:

Unaccounted For Water (UFW) is the difference between the volume of water delivered into a network and the volume of water that can be accounted for by legitimate consumption, whereas Non-Revenue Water (NRW) is the difference between the volumes of water delivered into a network and billed consumption.

JW over the years has been expressing water losses using the above UFW methodology and included the authorised unbilled consumption such as consumption in the informal settlements and the portion of consumption in deemed areas. The migration towards the NRW methodology will exclude the unbilled consumption in deemed areas and informal settlements, as per method below:

NRW = UFW+unbilled authorised consumption, i.e (water which is accounted for, but no revenue is derived.)

In the 2013/14 FY, JW will invest R432 million towards programmes that aim to reduce water losses. A mixture of technical, social and financial interventions will be implemented – aiming to reduce current UFW of 29.5% to 22% by 2016/17. The expected water savings will amount to a financial value of R368 million achieved by 2014/15. The reported annual net water losses at the end of 2011/12 FY were R301 million. Key Projects that will contribute to these savings are:

5.2.2 Pressure-Management Project

Pressure management is an effective way to control the amount of water lost in a system. This can be implemented without compromising the levels of service at the target or critical points. The aim of the programme is to reduce excess night-time water pressures in order to decrease background (small) leaks and to limit unnecessary pipe bursts. Elimination of pipe bursts improves quality of life in households in that there is a continuous supply. A small reduction in pressure can mean a significant reduction in real losses through leaks. Projected potential water savings from this project are 35 843 Ml per annum which is equivalent to R180 million/year).

5.2.3 Water-Pipe Replacement Project

The water pipe-replacement programme within JW is one of the key strategies aimed at combating water losses and improving the levels of service through the reduction of pipe bursts. To date, 3 phases of the programme have been implemented – which resulted in a generic prioritisation of suburbs targeted for the pipe-replacement programme from June 2008 to August 2012. A total of 21 suburbs have had about 200 km of pipelines replaced at a cost of over R200 million – over and above the dedicated Soweto and Alexandra Infrastructure Renewal Projects.

Box 1 Water demand management and unaccounted for water (JW, 2013, 46).

2. Surfacing invisible work

> Information systems encode and embed work (Star, 1999, 385).

Star reflects that infrastructure is embedded in other structures, social arrangements and technologies (1999: 381). This is what she calls the "invisible collage" of technical and routine work processes in the practice of infrastructure (Star, 1999: 384). Star comments on the invisible work of, for example, the communication systems of secretaries, which physical scientists might not deem "real science" but which are essential to the smooth functioning of the formal work stream in an organization (Star, 1999: 386). The technical work of infrastructure is instructive about city functions because of the close historical relationship between infrastructure and city planning (Neumann & Smith, 2010: 23).

Rawls observes that "methods of practice" are revealing of how particular social groups make sense of their world. Unravelling these often requires an approach called "tracing" (Rawls, 2011: 90). Everyday infrastructure practices may include information or decision systems such as spatial decisions tools or asset management systems, as well as written texts and mundane speech activities (Atkinson, 1988: 454). Tracing or surfacing these practices as invisible work, in Star's terms (1999a; 386), reflects the broader anthropology of infrastructure as a metaphor for analyzing the work of politicians, technocrats, economists, engineers and planners behind the physical systems, such as pipes or roads (Larkin, 2013: 327).

An important precedent for studying the "political rationalities" behind technologies is Foucault's genealogy of the state, where he develops his concept of governmentality (2010b: 70). Foucault's interest is government as a society, "not that kind of cold monster in history" (1977-78: 248), and he uses governmentality to understand government beyond a force of domination, but instead, as a mode of self-governance. In the concept of governmentality, Foucault attempts to capture the thinking and practices of government (Bye, 2015: 396), or as Roy reflects, the "art of government" (2009: 160). While borne out of Foucault's earlier work on power, self-control and liberties, governmentality is also a specific call for studying the political rationalities behind the apparatus of government (2010: 70).

Urban infrastructure as a technology and apparatus of government, in Foucault's sense, therefore reveals its rationalities and how it thinks (Foucault, 2008: 86, 2007: 358). Star's ethnography echoes Foucault by foregrounding actual work practices, such as spatial decision-making or economic valuation information systems (Foucault, 1977-78; Star, 1999: 387). This becomes clearer in Star's provocation relating to the paradoxes of infrastructure, and why some systems function and others do not, or why systems that are no longer functional continue to be used (Star, 1999: 387).

3. Understanding the paradoxes of infrastructure

> [O]nly by describing both the production and hidden task of articulation, together and recursively, can we understand why some systems work and others not (Star, 1999: 387).

Star's third trick is about understanding the paradoxes of infrastructure that relate to the obstacles to use or functionality, such as users' struggles with information technology (1999: 386). In addition, Star conducts an enquiry into the hidden assemblage of systems, such as desktop resources or computer memory, which might lessen the functionality of infrastructure (1999: 387). Similar work by Lauren Eastwood shows that the complexity of institutions is often in the process of "what actually happens" (2006, 2013). In her institutional ethnography of the United Nations (UN) Forestry Forum, Eastwood reflects on the practical politics of documentation and the wording of documents, which affect the politics and production of development work (2006). Eastwood's analysis reveals the UN as more than a "paper factory" and shows how texts and institutional discourse can be sites of key struggles within the UN, and practitioners' attempts to influence meaning are integral to the making of environmental policy (Eastwood, 2006).

4.4 A method framework

Taking Star's cue, the following sections consider the techniques or methods that practitioners use in their infrastructure practice for constructing information about, and assessing, infrastructure functions. Star's way of unfreezing infrastructure can be utilized for foregrounding methods that infrastructure practitioners use in their daily work and practice. It is helpful to situate infrastructure practice methods, beyond analytical arguments, using a simple heuristic of service delivery. Figure 2 is an example heuristic that applies Star's idea of unfreezing to foreground the "invisible work", such as spatial decision-making and economic assessments, that exist behind infrastructure services. While not the only ones available, these methods feature commonly in the planning and evaluation of urban infrastructure, used particularly by those promoting multifunctional Ideas.

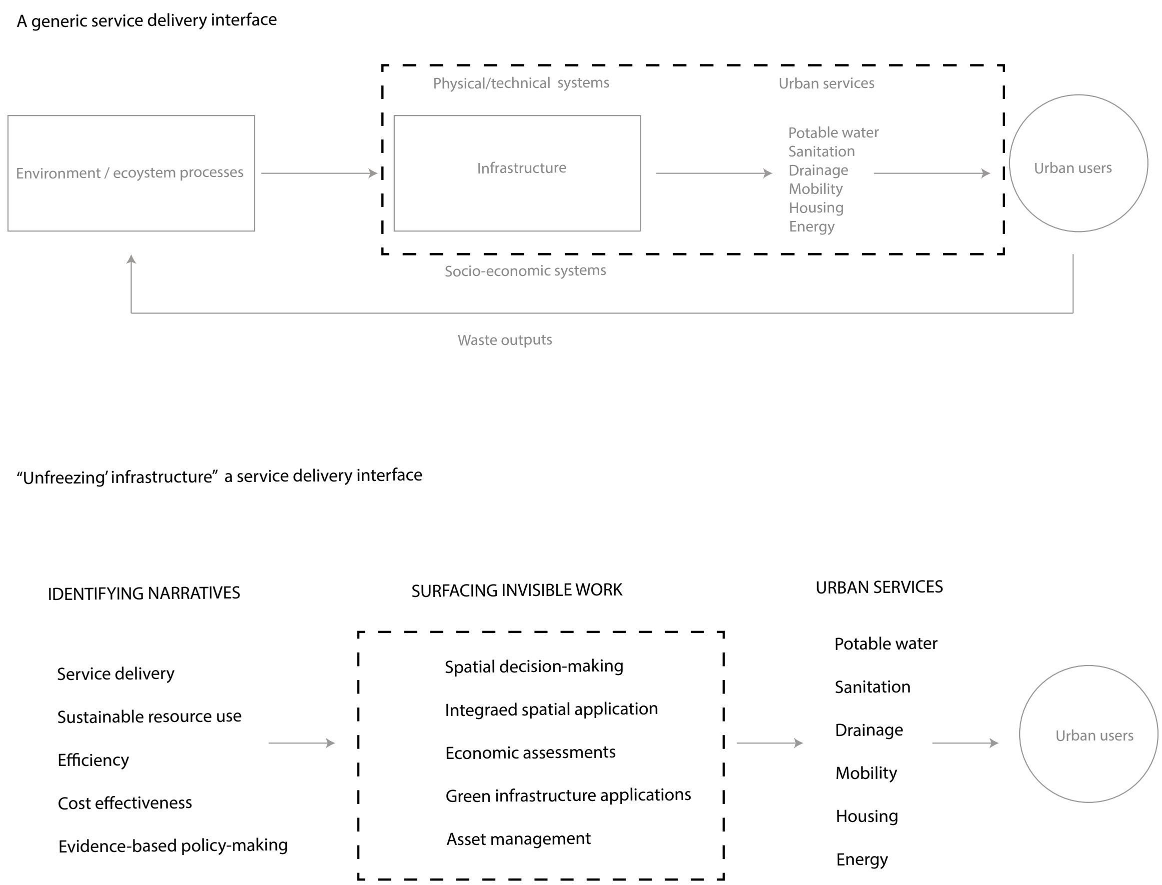


Figure 2 Using infrastructure practice as knowledge

4.5 Methods for investigating multifunctional infrastructure

The following section critically assess in more detail how practitioners use methods to investigate multifunctional infrastructure. The focus is generally on methods used in environmental planning, as this is the discipline that assesses how structural components of physical landscapes guide decision processes and practices (Thorne, 1993: 26). While many methods exist in their own realm, there is a growing fusion of decision-making applications as planners attempt to balance various demands for multifunctional infrastructure (Lovell & Taylor, 2013: 1453).

Spatial decision-making

As a physical phenomenon, urban infrastructure requires methods that can document how different functions manifest in space. The spatial decision-making processes include a suite of representation and analysis methods, together with heuristic devices that organize, describe and assess the interdependence of human–environment relations (Thorne, 1993: 30-21; Weller, 2008: 5). Spatial planning methods generally fall into two general categories, human-based exploratory graphical methods (cartography) and automated analysis tools (Openshaw, 1999: 4). Some people consider cartography to be "geographic information, [presented] in a manner that combines the scientific with the artistic" (Goodchild, 2010: 4). It is a useful indication of how humans perceive and manipulate space (Gold: 1992: 227) but has limitations in managing high levels of multivariate data complexity compared with automated systems (Goodchild, 2010: 3).

Automated spatial analysis is useful for studying the categorization of complex phenomena with multiple variables and large data volumes (Openshaw, 1999: 3). Developments such as Geographic Information Systems (GIS) software have contributed to the growing automation of spatial evidence decision-making (Goodchild, 2010: 13). Automation requires specific data, resources and skills, and precludes certain contexts where empirical data or specific software tools are not readily available (Lovell &Taylor, 2013: 1454; Goodchild, 2010: 13).

Infrastructure practitioners use spatial planning in a wide range of applications, from capital investment prioritization to the location of services (Klein et al, 2012; Todes, 2012). The focus of spatial decision-making is generally physical assessments of location, service delivery, and the form and structure of infrastructure (Albrechts, 2010: 4). From a multifunctional perspective, spatial decision-making has the potential for representing the harmonization of land use and physical space more broadly for space-using functions (Albrechts, 2010: 4). Spatial texts provide important interrogation points for critically reflecting on the spatial knowledge and methods of planning practitioners in response to urban sustainability. Spatial decision-making in infrastructure practice can therefore be an important database of how practitioners respond to sustainability as a concept or value. From a cultural geography perspective, however, the assumption that data interpretations provide single "truths" disregards the social processes that render landscapes non-neutral "containers" (Tilley, 1994: 9; Olwig, 2003).

Reflecting on some spatial decision developments highlights the knowledge opportunities of interrogating spatial texts. A key spatial evidence-generation development is the inclusion of prioritization methods for different functions. This is a response to the failure of spatial representation in prioritizing different functions, i.e. the provision and location of certain services. There is a growing fusion of GIS and multi-criteria decision-making (MCDA) to assess "the alternative courses of action among which decision-makers must choose action (what to do) and location (where to do it)" (Malczewski, 2006: 708). Explicit spatial alternatives include alternative sites for locating facilities, alternative location-allocation patterns and alternative patterns of land use-suitability (Malczeswki, 2006: 708). Implementing alternative decisions often has significant spatial implications and externalities elsewhere (Malczewski 2006: 708), but in many decision situations, however, the spatial component of an alternative decision is not present explicitly (Malczewski , 2006: 708). Greenberg challenges the metropolitan governments in Gauteng's belief in "evidence-based policy-making" as a tool for creating formal infrastructure (2010: 31), since it often leads to un-thought-through consequences, for example, evictions from informal settlements. There is similar evidence of the promotion of spatial decision methods by academic planners to shape the physical dynamics in which urban regions evolve (Healey, 2009: 440). Greenberg's caution is relevant to the global popularity of using spatial planning to guide infrastructure investment in metropolitan areas (Magni, 2013: 1; Wray & Cheruiyot, 2015: 14).

Reflecting on spatial decision-making methods helps to examine the rationalities of integrating functions in space, and the cultural practice underlying the assumptions and implications of the tools behind infrastructure such as GIS-MCDA (Jankowski & Nyerges, 2001; Malczewski, 2006: 718).

Integrated spatial applications

Early spatial models have limitations such as insufficient data size or lags in software processing capacity. For example, models that focus on a building and neighborhood scale may not be able to include "various dimensions of the physical urban form, such as lot or property tax size, street orientation, tree size and canopy girth, configuration, and ground coverage" (Ko & Radke, 2013: 3). In response to such limitations, spatial planners might also apply statistical models of multiple variables for assessing the correlation of attributes, such as urban form and residential energy use (Ko & Radke, 2013: 3).

Integrated applications of urban spatial modeling methods are part of a wider attempt to understand the relationship between spatial–temporal patterns of urbanization and ecological processes (Goodchild, 2010: 3). By including various metrics, such as land use characterization and landscape processes, integrated approaches assist in synthesizing complex data and managing uncertainty in abstract models (Lovell & Johnston, 2009: 24). Increasingly, environmental planners are also engaging communities to manage uncertainty by identifying place-based information at a site scale (Lovell & Taylor, 2013: 1450). However, the application of GIS to multi-criteria models is still highly dependent on data contexts. For instance, to extract variables from 2D and 3D information for the Sacramento region, Ko and Radke utilize LiDAR4 data, which requires a data-rich context (Ko & Radke, 2013: 3-4).

The limitations of data-rich environmental planning methods are evident in attempts to extrapolate MCDM spatial models across contexts. For example, an attempt by researchers to carry out a 5-year investigation of resource flows encounters in the Gauteng City-Region (GCR) faces not only data challenges but also difficulties in method extrapolation. The GCR project states its intention to model "resource flows required for and produced by this fast-growing region, and the infrastructure networks that traverse and structure this massive urban formation" (GCRO, 2011: 1). The disciplinary influences for the GCR assessment included methods from the discipline Industrial Ecology of quantifying and modelling resource flows in cities and city regions through urban built infrastructure (Barles, 2009; Kennedy et al, 2007). Conceptually, the GCR work is similar to that done in Sacramento in that city's attempt to build a model of interrelationships between resources use and infrastructure at an urban scale (GCRO, 2011: 6; Ko & Radke, 2013).

The GCR's application of various international resource measurement methods encounters challenges, however, of data availability and incomparable data categories (Musango, 2011: 38). A common limitation of extrapolating environmental planning methods from other contexts is the ability of government to generate and capture valid data. For instance, municipal and regional waste collection data in the GCR often exclude informal "wastepickers" who collect, recycle and divert different waste, but are overlooked in state waste sectors' auditing frameworks, so waste flows cannot be accurately account for.

The process of studying what practitioners actually do reveals how they manage error and uncertainty in infrastructure planning. The data anomalies also point to other issues related to how infrastructure decision-makers understand and manage the aggregate pattern of resources and services. For example, the spatial outputs for Orange Farm, a flood-prone informal settlement in Johannesburg, indicate a large part of the settlement is without stormwater infrastructure (Figure 3). Spatial data about informal settlements in South Africa is often problematic because informal infrastructure may not exist, or it may be unaccounted for in spatial datasets.

Very often, even where stormwater infrastructure does exist, the technical dimensions are either unknown or have not been classified. The spatial conclusions for Orange Farm imply poor stormwater data coverage, yet the technical attributes of “known” stormwater infrastructure, or “stormwater pipes”, is between 1-1 900 mm or 2 750-6 000 mm in width, which implies there is little incorporation of alternatives such as SUDS in the existing configurations.

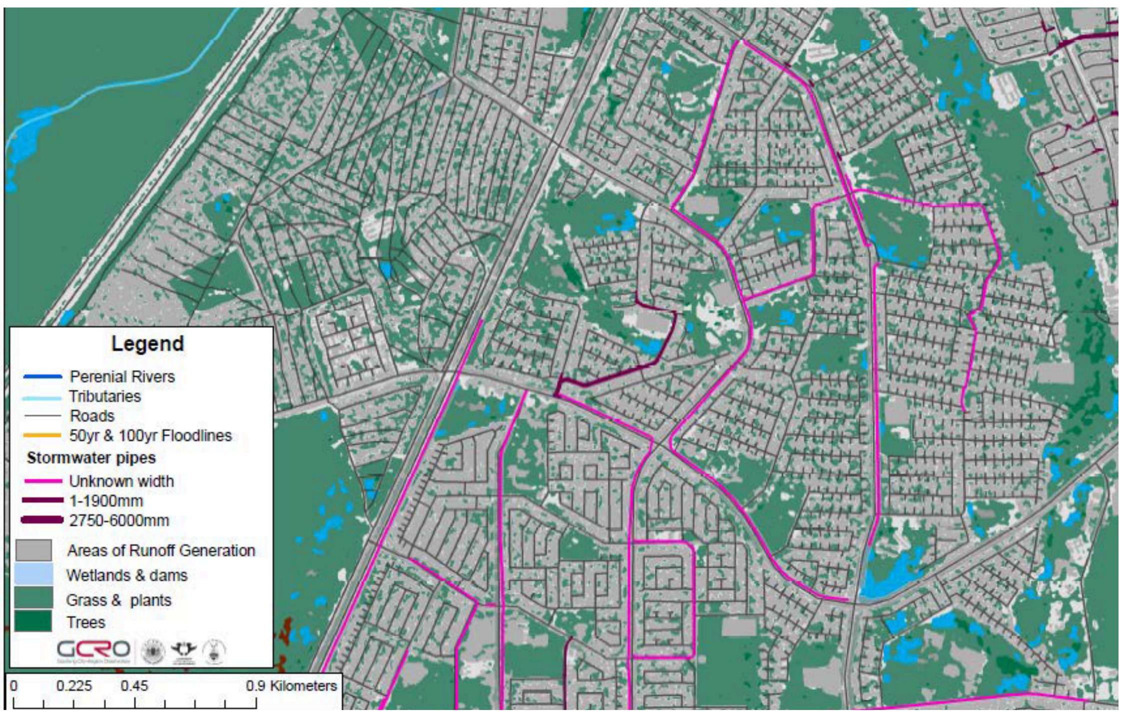


Figure 3 Hydrology of Orange Farm
Draft rendering indicating areas of runoff generation and stormwater infrastructure (GCRO, 2013a)

The spatial interpolation exercise questions, therefore, whether, in the event of absent or malfunctioning stormwater infrastructure, transport thoroughfares (i.e. roads) are the *de* *facto* channels for stormwater flows. Further possibilities exist because of the juxtaposition of "areas of runoff generation" with "grass and plants" and "trees", as data categories by the Johannesburg Roads Agency (JRA).

Data anomalies within spatial applications are a critical source of information about infrastructure decisions. In the above examples, geospatial data and integrated modeling exercises of stormwater infrastructure raise questions of how infrastructure practitioners manage and, crucially, represent, error and uncertainty. Spatial information as a collective communication tool therefore contains essential insights into how practitioners perceive urban infrastructure and the capacity of the decision-making tools in use.

Economic assessments

Economic assessments of urban infrastructure apply methods of valuing the basket of goods and services in a given market in quantitative terms. Increasingly, market valuation is also featuring as an approach for quantifying "ecosystem services" and prioritizing biophysical systems in planning and decision-making. The major global project, the Millennium Ecosystem Assessment (MEA), and its sub-global assessments (SGAs), are seminal in "build[ing] interest in using ecosystem services approaches to identify links between ecosystems and economic and human development" (Layke et al, 2012), or as Norgaard emphasizes, "awakening" society to thinking more strategically about nature (2010: 121). Ecosystem services are capable of making valuable contributions to human wellbeing and to the accomplishment of long-term development goals. Norgaard's metaphor refers to the benefits that humans derive from ecosystems, such as flood alleviation, cooling of heat islands, carbon capture, water filtration, and local food production, among others (see also Tzoulas et al, 2007; Mell & Roe, 2010).

One of the intentions of the ecosystem services approach is to assist in the conceptual evolution away from viewing green assets only in terms of the aesthetics of human settlements, or in terms of environmental justice concerns. The application of economic techniques to quantifying ecosystem services intends to develop a common currency for decision-makers, and it is particularly appealing for budget comparisons across regions (De Wit et al, 2012). A burgeoning body of quantitative work focuses on generating values, quantifiable metrics that are tangible in accounting and economic terms (Constanza, 1998; de Groot et al, 2002).

Some scholars (for example, Layke et al 2012; and Pickett & Cadenasso, 2002) reflect, however, that ecosystem service applications often struggle, due to rudimentary knowledge bases and a lack of methods, to develop metrics or indicators for tracking and communicating ecosystem services. A common premise is that a failure to acknowledge the benefits that ecosystem services supply to both ecological and social systems is an externalization problem, from which we can now profit (James et al, 2009; Jansson & Polasky, 2010; Sandström, 2002). The benefit for public coffers lies in quantifying a latent market good, as a GCRO report reflects:

> Nuanced quantification of the extent, form and quality of green assets, and the value of each in terms of their infrastructure functionality, is critical if policy-makers are to conclude, with a reasonable degree of confidence, which vegetated forms should receive targeted fiscal support (GCRO, 2013: 13).

In South Africa, De Wit and colleagues produce an economic assessment to value Cape Town's natural environment in order to overcome fiscal structures and institutional path dependencies of the environment as a non-essential fiscal allocation (De Wit et al, 2009). The study makes the case, for instance, that investments in ecosystem goods and services can reduce local government maintenance budgets, while fiscal allocations to the natural environment may unlock new economic opportunities (GCRO, 2016: 45).

However, monetary valuations of the environment face a number challenges. First, there are divergent ethical positions about commodification. Some argue that ecosystems are intrinsically valuable, regardless of the value humans place on them, and commodification in terms of ecosystem services is fundamentally at odds with the true value or worth of "nature". The Landscape Architecture Foundation's (LAF) landscape performance series is an example of measuring performance, not in terms of ecosystem services, but according to an alternative quantification of environmental, social and economic benefits (Yang & Binder, 2016: 315). The LAF series is significant not only as a platform for research and knowledge dissemination, but also for quantifying or assigning some value, such as carbon sequestration value, or social value, to real-world projects (Yang & Binder, 2016: 315-216). While many LAF studies do assign an economic value to landscape performance, the process of quantification is more about practical solutions and, specifically, using case studies as the primary form of education, innovation and testing of performance (Francis, 1999: 5).

A second objection relates to the level of information consumers have available, since ecological importance is a function of complex factors and it varies for different environmental conditions (Francis, 1999). The limitations are a lack of adequate understanding (about the cause-and-effect linkages between value and commodity), and how we then make a trade-off in assigning different ecosystem values, which may have biases. For example, grasses native to California are valued for their "intrinsic" value, i.e.

as indigenous species, but they are no longer performing the functions in habitats that people valued historically, such as marsh accretion. Studies indicate that non-native marsh grasses are better short-term options for assisting marsh accretion than indigenous grasses. This is relevant to dealing with sea level rise, and challenges our assumptions about constant ecosystem value.

A major assumption of ecosystem service valuation is that the economic multipliers of ecosystem investment become evident in an economic market (De Wit et al., 2012). A related assumption is that reducing ecosystem services to a set of quantitative values is sufficient to affect decision-making. It is often difficult to expand beyond narrow market economics, which may not adequately address cultural issues, although there have been some attempts to capture both ecosystem services and disservices (Lovell et al, 2013: 1459).[15]

Asset management (AM)

Asset management (AM), or Infrastructure Asset Management (IAM), is emerging as a key decision-making method and management process for urban infrastructure. While precise definitions vary, AM is broadly a management and decision-making process relating to physical infrastructure assets (Marlow et al, 2010; Leitão et al, 2014: 1). AM often includes the application of various other management, financial, economic, engineering and related practices to the management of physical infrastructure assets (Marlow et al, 2010).

In practical terms, AM is therefore the decision-making or management processes that assimilate information of the entire life cycle (creation, maintenance, renewal, expansion, decommissioning) of a physical system that delivers services (Leitão et al, 2014: 1). The life cycle perspective is key to AM, which generally spans multi-year capital investment for infrastructure projects, including details of the long-term funding and operational policies necessary to sustain the performance of infrastructure into the future (Harlow, 2014).

AM proponents argue that the life cycle perspective is a shift away from previous approaches that separate infrastructure design, on the one hand, and operations and maintenance on the other (Van der Lei, 2012). The US Environmental Protection Agency, for example, interprets AM as “managing infrastructure capital assets to minimize the total cost of owning and operating them, while delivering the service levels

[15] Ecosystem disservices include invasive species that threaten other ecosystem services, spread of allergens or toxins in plants, wild animals transmitting diseases, physical damage to built infrastructure by decomposition or tree roots, depletion of water resources due to irrigation, nutrient runoff from fertilization, or spread of contaminants through soil and plant material (Lovell et al, 2013: 1459).

customers desire" (EPA, 2002). The life cycle perspective has issues for deferred maintenance, creating the challenge for infrastructure managers of aimplementing large repair budgets while maintaining a constant level of service and operations (Sitzabee & Harnly, 2013; 46).

Marlow and colleagues argue that AM is a way of ensuring there is sufficient investment in the physical assets used to deliver services (2010, 1245). The deferral of necessary investment is short-term and narrow infrastructure management, so AM practitioners use the life cycle perspective to ensure adequate and sustainable levels of service in the long term (Marlow et al, 2010: 1245; Cardoso et al, 2012: 2703). Therefore, the Institute of Asset Management in the UK defines AM as:

> Systematic and coordinated activities and practices through which an organization optimally and sustainably manages its assets and asset systems, their associated performance, risks and expenditures over their life cycles for the purpose of achieving its organizational strategic plan (Van der Lei, 2010: 15).

AM narratives about infrastructure sustainability do, however, encompass a number of different objectives. One objective is maximizing the value of an asset over its whole life, especially where infrastructure managers such as utilities operate as businesses, which need to ensure efficient economic returns on investment (Marlow et al, 2010: 1248):

> The application of strategic asset management in the municipal sector is of growing concern and importance. Increasingly, municipalities are faced with shrinking facility budgets while, at the same time, having to provide the most suitable properties in support of core service delivery requirements (Jolicoeur & Barret, 2004).

The attraction of asset management planning is evident in promises by global companies "to ensure long-term affordability and reduce potential for unintended costs" (AECOM, 2014). The AECOM report, *Climate change, infrastructure and asset management in the Eastern Riverina* (2014), regards asset management as an appealing tool that links performance measures, targets and infrastructure assets, with the practical goal of minimizing costs and maximizing efficiency. AECOM's framing of asset management reflects how AM is becoming a key part of the lucrative business of providing the physical infrastructure, equipment and services needed to sustain the broader spectrum of valuable services and goods upon which human communities depend (Grigg, 2016: 710).

Increasingly, AM encompasses sustainability in terms of the need to cope with system changes or factors affecting service provision, including environmental technological developments, changing social expectations and various forms of risk (Cardoso et al, 2012: 2702). In general, "sustainability of service provision" implies "that all assets are maintained and able to meet current and future users' needs, including economic and financial aspects, for all the utility activities" (Cardoso et al, 2012: 2704). Concerns about climate change and resource constraints also often feature in AM narratives of the sustainability of infrastructure, in terms of large-scale changes or risks (Cardoso et al, 2012: 2704).

AM systems typically define Level of Service (LoS) and investment or inputs, such as availability of funding or other resources required to sustain these services. At the San Francisco Public Utilities Commission (SFPUC), asset management models for the Sewer System Improvement Program (SSIP) "provide an iterative system whereby capital investments and operations and maintenance protocols are continually refined over time" (SFPUC, 2010: 23). While the SFPUC employs several broader capital decision-making programs, the SSIP details the sewer network and describes the different sewer system categories in terms of the dual functioning of capital improvements, i.e. the collection system and wastewater treatment facilities (SSIP, 2010: 3):

Collection system includes:
- Pipelines
- Collection system lift stations
- Transport/storage system
- Influent pump stations

Wastewater treatment facilities include:
- Liquid treatment processes
- Solids treatment processes
- Deepwater outfalls

Significantly, the SFPUC views its asset management approach as an overarching planning, management and evaluation system that takes into account the long term economic, environmental and social impacts of its business activities (SFPUC, 2011: ii). While there are a number of supporting components, SSIP is the core tool that the SFPUC uses in its efforts to rebrand capital improvements as "Grey Green and Clean" (SFPUC, 2011). This rebranding embraces "inclusive … environmental and community interests and sustains the resources entrusted to the SFPUC's care" (SFPUC, 2011: ii). Although the rebranding is part of the utility's broader sustainability agenda, its underlying imperative is services, evident in the SFPUC's statement that integrating grey and green infrastructure is intended to enable "system-wide change in the utilities' levels of services of power, water and waste" (SFPUC, 2013).

Indicatively, the SSIP utilizes Level of Service (LOS), primarily, including regulatory permit compliance, system reliability and functionality, as well as sustainable operations of the city's sewer system, to evaluate capital improvements (SFPUC, 2012: 3). The evaluation of LOS importantly happens in the utility's asset management models that rely on specific technical and operational information for assessing the applicability of sustainability criteria to capital projects. A key insight here is that while the SFPUC has an overall sustainability imperative, the underlying performance criterion is the extent to which the utility is able to "manage and plan it services to customers" (SFPUC, 2011: A1).

There is similar evidence from the City of Johannesburg (CoJ), where experiments with AM take the form of Infrastructure Asset Management Plans (IAMPS). These are methods of identifying a given department's existing assets and monitoring their condition, as well as managing the necessary interventions to maximize an asset's expected lifespan (Magni, 2013: 8). These planning methods will be discussed in more detail in Chapter 6, which shows there is an important history of planning experimentation in the CoJ in response to infrastructure capacity deficits, historical inequality and growth pressures. Tracing this history of experimentation through the methods of infrastructure practice contributes insights about the capacity of the CoJ to address its future pressures.

4.6 Conclusions

> But just how should we experience the world? And then how should we articulate it? Are there examples of the expanded perspective? What would it look, feel, smell, or sound like? How do we know if we are approaching it? (Næss, 1989: 20).

This chapter asserts, along with Næss and several other scholars, that a starting point is to understand infrastructure as a material process of pipes and physical systems that interface with the social systems, of institutions, politics and cultural experiences (Anand, 2014; Geels & Kemp, 2007; Graham, 2000, 2010). This chapter considers what a cultural approach to studying infrastructure implies, in practice, and which methods tell us how practitioners understand, respond and prioritize multifunctional infrastructure.

Building on Star's suggestions, this chapter shows that a valuable entry-point is taking the planning methods that practitioners use in their daily work as knowledge. Often, these are the everyday practices or routines that go unnoticed, behind-the-scenes. While Star's tricks of unfreezing infrastructure are appealing, her ethnography may also come across as meta-theoretical and jargonistic. The chapter therefore suggests a service delivery interface as a simple heuristic within which to foreground the methods or techniques of infrastructure practice.

As urban governments confront major infrastructure challenges and consider sustainability as a strategic value, important questions arise about the available techniques or methods to realize sustainability as a value. The following chapter discusses in detail how, in Johannesburg, the methods in use by infrastructure practitioners present important evidence of how capacity to realize sustainability values manifests.

PART 3 CASE STUDY

Chapter 5: Johannesburg

5.1 Introduction

Johannesburg is South Africa's economic powerhouse and most populous city, and home to almost 5 million people, an increase of 11.6% since 2011 (CoJ, 2018a: 14). Economic migration, rather than births, fuels this "city of migrants", which is likely to receive another 3 million people by 2037 (Crush, 2005: 113; CoJ, 2017a: 101; GCRO, 2013b). More than a third of the population of the wider Gauteng province lives in Johannesburg, making it the most-dense urban city region in southern Africa.

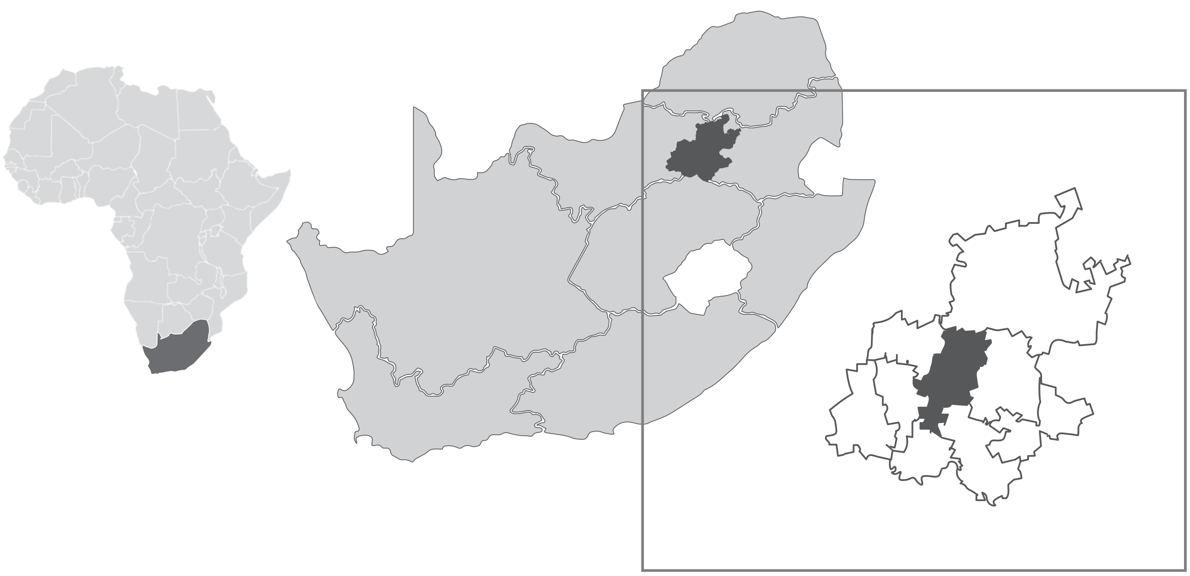


Figure 4 Johannesburg within the regional context

Despite access to services in the region being the highest nationally, many households lack sufficient infrastructure connections. Many in the poorest communities walk to fetch water, while approximately 14 500 households continue to rely on bucket toilets (GCRO, 2015: 16; CoJ, 2016a: 32-33). Services inequality is one of the perverse legacies of South Africa's apartheid history, and together with the growth of informal housing on Johannesburg's peripheries, creates the challenge of where to densify infrastructure.

A rapidly expanding population means that government is under pressure to manage its changing spatial environment, furnish the infrastructure networks for industry and business, and roll-out service delivery programs as a matter of urgency. Doing this will consume resources and presents government with a number of sustainability conundrums in an already constrained physical environment, especially because the Johannesburg region lacks a navigable water body and relies on some of the most extensive inter-basin transfers in the world.

There are also the sinister externalities of Johannesburg's industrial history, including the decanting of acidic mine water from dormant gold mines, pollution from illegal industrial discharges, and leaking sewers and storm runoff. Much of Johannesburg's infrastructure is also in urgent need of replacement, especially in older part of the inner city. This reflects a crisis of deferred maintenance that poses questions for the potential trade-offs between new capital outlays, clearing backlogs and fulfilling system renewal targets in a constrained fiscal environment.

There is an impressive body of research into the infrastructure challenges facing Johannesburg in the realization of its rights-based redress and access expansion agendas since South Africa's democratic transition in the 1990s (Beall et al, 2002; Parnell & Robinson, 2006; Harrison et al, 2015; Pieterse, 2017). There are also various evolving contributions that examine Johannesburg's strategic planning environment in terms of the sustainability of the wider region, particularly from the GCRO (Gauteng City-Region Observatory) (Todes, 2012; Schäffler & Swilling, 2013; Götz & Schäffler, 2015; GCRO, 2017; Pieterse, 2017a).[16]. The first part of this chapter reflects some of this scholarship. In particular it presents an overview of Johannesburg's infrastructure challenges using water as a focal point for re-reading some familiar issues from the City's perspective.

However, missing from the existing research is a detailed ethnographic reading of the

[16] GCRO is a prominent research agency undertaking research on "sustainability transitions" within the Gauteng City-Region (GCR), including Johannesburg (GCRO, 2017).

hidden practices, systems and knowledges that lie as a substrate below the way the City of Johannesburg appears to be confronting its infrastructure challenges. To better understand the prospects for a shift to urban sustainability, there is a need to uncover what base conditions exist in the way infrastructure decision-making works.

It is important to note that what follows is not an account of how normative ideals of sustainability have or have not been taken up in Johannesburg's policies and projects. There is an understandable expectation that an analysis of a city's urban sustainability related infrastructure practice ought to proceed through an assessment of how the city applies urban sustainability ideology and theory, experimenting with sustainability principles and designs in this or that regulation or project (Patel, 2014: 17; Ziervogel & Parnell, 2012; Pieterse, 2011). But this would be a normative reading, one that presupposes that the underlying conditions for an urban sustainability agenda in infrastructure systems and practices are *a priori* in place, and that the correct point of enquiry is to ask only whether and how sustainability values have been adopted and applied. Such analyses might well yield some insights into the way that urban sustainability agendas manifest in practice. However, my interests are in a different perspective that takes historical and existing infrastructure practice on its own terms, and foregrounds the ways in which cities are grappling with the more fundamental structures and mechanisms – the viscera – internal to their infrastructure planning systems, that in turn lay the bedrock for urban sustainability choices.

This case study therefore proceeds as a counterbalance to the typical assumption of research ideologically precommitted to urban sustainability. It seeks out not a perspective of how prearranged theories and frameworks have been absorbed and manifested, but rather an ethno-methodological reading of the infrastructure histories and practice that underpin how urban sustainability agendas might materialise in the Johannesburg context.

The second part of the chapter applies Star's notion of unfreezing to Johannesburg's infrastructure planning context. It proceeds to interrogate the difficult questions or conundrums facing the city in relation to sustainability. These often derive from competing ideologies and discourses, but also from more prosaic urban management issues, such as deferred maintenance and fiscal constraints. An updated historical analysis of Johannesburg's infrastructure shows the rise of infrastructure prioritization methods which, while not always entirely successful, are efforts by the City to address competing demands and should be included in analyses of the ways sustainability value shifts influence planning shifts. The Consolidated Infrastructure Plan (CIP), an unfolding process, offers an opportunity to reinvigorate the history of infrastructure planning in Johannesburg and the shifts underway towards integrated planning. These shifts reveal the ways the municipality is creating the decision-making capacity for sustainability and the infrastructure practices that emerge to absorb shifting values.

This chapter's analysis includes a critical review of existing scholarship and of the City's planning documents, decision-making tools and various others municipal texts. In addition, information from a series of interviews done between 2013 and 2018 helps to clarify facts about the City's history and planning context. These interviews involve municipal officials, former officials, planners and consultants from the private sector (see Appendix C). Where interviewees express ethical views, these are reproduced anonymously, unless participants agree in advance to full disclosure.

5.2 A call for revisiting infrastructure challenges, from the City's perspective

Johannesburg's history reveals its hydrological incongruence. The city owes its existence, somewhat fortuitously, to the discovery in 1886 of rich gold deposits in the Witwatersrand (ridge of white waters), a rocky ridge that extends in an east–west direction across the region (Du Plessis, 2017; Bobbins & Trangos, 2018). Johannesburg lies at the head of a water divide, but small rivers, underground springs and wetlands are the only immediate water sources (Dippenaar, 2015: 26; Tempelhoff, 2000: 90). Issues relating to water supply uncertainties and water quality are some of the most acute infrastructure challenges facing Johannesburg (Tempelhoff, 2000, 2003, 2009).

Having no navigable body of water in the vicinity, the city relies instead on extensive inter-basin water transfer schemes to support its population, sustain its growth, and manage effluent outflows. The most significant of these is the Lesotho Highlands Water Project (LHWP), which is also one of the largest such schemes globally. Water from the upper reaches of the Senqu river, in the Lesotho Highlands, is transferred approximately 90 km to the Ash River, and another 200 km to the Vaal Dam (Turton et al, 2006: 323; Hobbs et al, 2013; Dippenaar, 2015: 47). A second phase of the LHWP is under construction, which, according to the former Department of Water Affairs (DWA) [17], is necessary to support the coalfields north of Johannesburg in the Waterberg area, and other expanding industrial developments [18] (DWA, 2010: 2).

Scientists emphasize the importance of a systems perspective in appreciating the complex components of augmentation and storage of Johannesburg's water supply mix. Johannesburg's bulk supplier, Rand Water, abstracts water from the Vaal Dam for

[17] The DWA became the Department of Water and Sanitation (DWS), following Presidential Proclamation Number 43 of 2014, which established various departments in new ministerial portfolios (PMG, 2014).

[18] These include Eskom power stations and Sasol petro-chemical plants on the Mpumalanga Highveld, the North-West and Free State goldfields, Kimberley, and several small towns' infrastructure and irrigation schemes (DWA, 2010: 2).

treatment at the Vereeninging and Zuikerbosch Purification and Primary Pumping stations (Rand Water, 2008: 30). Primary pumping involves pumping water approximately 180 – 360 meters to a main Booster Pumping Station (Zwartkopjes) and three satellite Booster Pumping Stations (Palmiet, Eikenhof and Mapleton) that elevate water a further 180 - 360 meters to reservoirs in Johannesburg (Mushongera, 2012). There are 58 reservoirs, which, using a mix of gravity-flow and repumping, distribute water to the extreme boundaries of Rand Water's supply area (Mushongera 2012; Rand Water, 2017). Further pumping schemes transfer water from Rand Water's reservoirs to a distribution network that supplies 'fit-to-drink' (potable) water to Johannesburg Water (JW), the municipal entity that functions as an independent company with the CoJ as sole shareholder (JW, 2016). Following procurement of bulk supply, JW distributes potable water via several reservoirs, water towers, water pump stations and distribution pipes across the city's seven administrative regions (JW, 2016).

Furthermore, the Vaal Dam is one component of the Integrated Vaal River System (IVRS), which supports not only Johannesburg, but also the other surrounding areas that make up South Africa's economic heartland. Several augmentation systems exist to help cater for these requirements. The Thukela–Vaal Augmentation Scheme (TVAS), for instance, pumps water upstream from the Tugela River into various storage dams (Turton et al, 2006: 321-325). Johannesburg also relies on important storage components, such as the Sterkfontein Dam, which feeds the IVRS if levels in the Vaal Dam are below minimum operating requirements. In 2015, after a strong El Niño event of prolonged drought, the reserve capacity from Sterkfontein was controversially released, requiring replenishment from the Thukela scheme (Muller, 2017: 10).

Concerns about future water supplies intersect, somewhat paradoxically, with the erratic, yet increasingly intense summer thunderstorms. A national drought triggers the City to implement water restrictions in 2016 (CoJ, 2016b), yet following wet weather conditions and heavy rainfall during 2017, Vaal Dam levels rise to see a lifting of earlier restrictions (Petterson, 2017). Fluctuating supply in the IVRS simultaneously results in an uncertain supply context and erratic flooding that damages infrastructure and threatens many vulnerable communities. While summer thunderstorms are seasonal phenomena for the Highveld Grassland climate (Dyson, 2009), researchers observe that Johannesburg experienced a decrease in the number of thunderstorms from 1960 to 2008, but a significant increase in average rainfall per storm (Fatti & Vogel, 2011: 59; Engelbrecht et al: 2011).

In February 2009, thunderstorms cause flooding along the Klipspruit River, killing at least two people, leaving more than 300 families homeless, and incurring approximately

R350 million [19] in disaster costs for the City (CoJ, 2009). As a result, there is a tendency to think of stormwater primarily in terms of flood risk and community disaster mitigation (Fatti & Vogel, 2011: 59). Research also demonstrates the implications of spatial changes, which further affect drainage patterns, as evident in periodic flooding on saturated ground due to Johannesburg's expanding urban footprint (Fatti & Patel, 2013: 16). While some policies aiming to address sprawl promote densification, the implication of reducing erven (plot) sizes is less on-site drainage capacity, altering run-off friction coefficients and concentration times (Buys & Aldous, 2009: 23).

A great deal of attention also focuses on Johannesburg as an "acidic water time bomb", referring to the decanting of polluted mine water into sewers, wastewater treatment works and natural systems (Staff reporter, 2010; Taylor, 2014; Saving Water SA, 2011). Acid Mine Drainage (AMD) occurs as a result of the reaction of polluted water from dormant gold mines and mine strata, with waste and oxygen. It becomes highly acidic with heavy concentrations of salts and metals (IMCAMD, 2010: McCarthy, 2010). AMD is a sinister legacy of Johannesburg's gold mining history, rendering water generally unusable and requiring costly treatment as well as large releases from the Vaal Dam for dilution (McCarthy, 2010).

Beyond the underlying causes and impacts of AMD (Hobbs, 2015; McCarthy, 2010), there is an evolving body of critical reflection on its hydro-political and governance dimensions as well as the disproportionate effects for particular communities and ecosystems (Bobbins et al, 2018; Coetzee et al, 2005; Turton, 2015). There are parallel concerns about eutrophication from wastewater treatment plants, industrial discharges and pollution from storm runoff (McCarthy & Venter, 2006; Oberholster, 2010; Oelofse, 2012; Turton, 2015). Harding reflects, however, that while these issues do receive some attention, there is generally insufficient scientific and political attention to specific issues, such as eutrophication (2008, 2010, 2015).

In light of South Africa's apartheid history, service delivery access is an important enquiry for critical research and debate. Despite comparative service delivery successes, Johannesburg still struggles with persistent infrastructure inequities, which often manifest spatially and reflect the impact of spatial planning as a form of racial control during apartheid. The Johannesburg metropolitan municipality is often critiqued as a product of neoliberalism that undermines structural transformation (Tomlinson et al, 2003; Winkler, 2009, 2011, 2012; Murray, 2004, 2008). A common scapegoat, particularly for critical leftists and political ecologists, is the corporate model of water service delivery that emerged following municipal amalgamation during South Africa's democratic transition

[19] Approximately $ 29 million at the time of writing.

(Bond, 2010; Bond & Dugard, 2008; Muller, 2007; Smith, 2006; Von Schnitzler, 2008), which not only embeds in Johannesburg an exclusionary geographical divide, but also creates resource inefficiencies and prohibitively high infrastructure costs (Harrison & Todes, 2001: 68-67; Murray, 2004: 142-143; CoJ, 2017a: 42).

While critical reflections on the politics of service delivery make important contributions, the practice of municipal infrastructure entails many complex decisions and often requires trade-offs between different priorities. Pieterse reflects that the tendency towards neoliberal castigation overlooks not only the complexities in planning, but also the work of the municipalities in mediating between urgent and competing delivery objectives (2017: 2).

There are caveats from some research, such as Anita von Schnitzler's, although also largely from a leftist critique, into the institutional decisions to implement prepaid water meters (2010, 2008), and others seeking to foreground the techno-bureaucratic processes underlying planning (Magni, 2013; Götz & Todes, 2014; Harrison et al, 2014; Muller, 2007; Cartwright & Marrengane, 2016; Pieterse, 2017). There are also evolving contributions, from GCRO, among others, that examine Johannesburg in terms of the sustainability of the wider city-region, responding to the general dominance of Cape Town as the subject of South African urban geography and sustainability planning research (GCRO, 2017; Schäffler & Swilling, 2013; Mosselson, 2017; Rogerson & Rogerson, 2015; Visser, 2013; Visser & Rogerson, 2014).

For sustainability scholars and practitioners, Johannesburg's water challenges are useful critiques for how the City is struggling to transition out of an unsustainable urban project, premised on an exploitative and resource-intensive industrial economy and growing beyond its means (Bond, 2007; Götz & Schäffler, 2015; Schäffler & Swilling, 2013). Normative analysis sustainability also benefits from the clear, albeit intermittent interest in urban sustainability as a strategic agenda in the City.

In 2014, the Johannesburg Stock Exchange (JSE) list its first green bond through the CoJ to fund "the implementation of its climate change mitigation strategy, a low carbon infrastructure, minimal resource reliance and increased natural resources" (JSE, 2014). The green bond move coincides with the Johannesburg's hosting of the C40 Cities Climate Leadership Group Mayors Summit, during which mayor at the time, Parks Tau, drives "resource efficiency" and green infrastructure development across the energy, transport, waste, housing and building sectors" (C40, 2015, JDA, 2014).

There is also a strong history of "greening initiatives", largely pertaining to tree planting, park and green space development, as well as reducing ecological disparity (CoJ, 2008a;

Schäffler et al, 2013: 5). These initiatives intersect with a momentum surrounding the City's future spatial visions that propose shifts to more efficiency and inclusive urban form in line with the principles of compact and transit-oriented development, as well as mixed-use urban nodes (Pienaar, 2016: Todes, 2012: 164). The City is also engaging with several external actors on opportunities relating to the "green economy", and idea gaining traction in the Department of Economic Development (DED), which is seeking "flagship" projects for green technologies (CoJ, 2016a: CSIR, 2018).

While such commitments may fit normative interpretations of how urban sustainability should manifest, a different perspective comes unpacking infrastructure practice. Using Susan Leigh Star's notion of "unfreezing", the following sections reassess the context of service delivery in Johannesburg and bring attention to the internal structures of the City as channels to the understanding the capacity for sustainability decisions.

5.3 Unfreezing infrastructure

The City of Johannesburg (CoJ) is a local government under the political leadership of the Democratic Alliance (DA). The DA assumes leadership of the City following the 2016 local government elections after twenty-two years under the African National Congress (ANC), the ruling political party in South Africa nationally. At the time of writing, there are evolving views on how the DA change-over in Johannesburg represents broader political dynamics, such as factionalism within the ANC (Mashele, 2016; Everatt, 2018).

As a local government, the City is the primary agent responsible for delivering basic services in its jurisdiction (RSA DPLG, 1998). Important legislative changes take place following South Africa's democratic transition in 1994, and local governments undergo a major process of institutional restructuring that sets up institutions, planning systems and narratives that coalesce around infrastructure and fundamentally shape the nature of service delivery. Understanding the role of local government in service delivery requires an explanation of South Africa's post-1994 context.

5.3.1 Post-1994

Key manifestations of apartheid, such as spatial segregation, the dislocation of communities and their deprivation of essential services, reflect the perverse role that planning can play as an instrument of social engineering (Turok, 1994: 243). In 1994, apartheid, or racial segregation by law, comes to an end in South Africa (Smith, 1992) and the transition to democracy ushers in significant political visions and new policies to allow all South Africans equal rights. The 1996 Bill of Rights in the South African Constitution states:

> Everyone has the right to an environment that is not harmful to their health or well-being ... everyone has the right to have to health care services, including reproductive health care; sufficient food and water; and social security (RSA, 1996).

One of the clearest representations of the new rights-based constitutional agenda is the attempt to eradicate former racial boundaries, including with respect to infrastructure. The new government's ubiquitous post-1994 "service delivery" agenda encapsulates these visions and implies the roll-out of housing, water, sanitation, electricity, roads and refuse collection to historically disadvantaged communities (RSA, 1996; ANC Manifesto, 2009; Turok, 2016: 12). The writing of the Constitution effects not only a robust rights-discourse, but also important changes in the institutional context of service delivery. While there are variations between rural and larger, especially, urban, municipalities in providing basic services, two fundamental, intersecting changes are the granting of governing autonomy to local governments, without interference from higher levels (Chipkin, 2002: 72; RSA 1996), and the mandating of delivery of "basic" services such as water, sanitation, local roads, stormwater drainage, refuse collection and electricity, to local government, which must:

> [deliver] accountable and democratically elected government for communities; … ensure the provision of services to communities in a sustainable manner; promote social and economic development; promote a safe and healthy environment; and encourage the participation of communities and community organizations in the business of local government (RSA, 1996).

The role of local government in service delivery reflects the ANC's "developmental" concept of governance, which is about strengthening grassroots participation in democracy (Binns & Nel, 2002: 921). The 1998 *White Paper on Local Government* explicitly defines the concept of developmental local government in term of a narrative of sustainable service delivery:

> Developmental local government is local government committed to working with citizens and groups within the community to find sustainable ways to meet their social, economic and material needs and improve the quality of their lives (RSA DPLG, 1998).

The granting of governance and financial autonomy to municipalities also means that large metropolitan cities – metros – become responsible for their own revenues (Pieterse, 2017: 2; Parnell, 2004: 380-381). Previously separate councils, city centres, former white municipalities, and black "townships", are amalgamated and brought into a single municipality (Everatt et al, 2004: iii; Wooldridge, 2002" 127). Fiscal integration is intended to address service backlogs in former black areas and connect these to essential household and community infrastructure (Turok, 2016: 12).

There are effectively two major processes of amalgamation that influence Johannesburg's relationship with its infrastructure. The Greater Johannesburg metro is restructured through a series of complex institutional adjustments from an initial 12 administrative bodies in the early 1990s. In 1995, a two-tier structure of 4 transitional Metropolitan Local Councils (MLCs) is formed under the umbrella of the Greater Johannesburg Transitional Metropolitan Council (GJTMC) (Beall et al, 2002: 107, 118; Bremner, 2000: 187). The transitional councils are part of an interim period of negotiating unification. Under the GJTMC, individual councils are responsible for collecting revenue from service provision and balancing their books on aggregate under the overarching metropolitan authority, which in turn provides bulk infrastructure connections (Cartwright & Marrengane, 2016: 8; Beall et al, 2002: 77-78).

The GJMTC model depends on stronger councils for fiscal support of redistributing resources in a historically unequal system. This is theoretically possible because, unlike other parts of the country, Johannesburg has a substantial wealthy population to enable cross-subsidizing of service delivery (Parnell, 2004: 385; Smith, 2006: 21; Beall et al, 2002: 77, 78). However, the overreliance on stronger councils leads to a debate about who should benefit from surplus revenue (Cartwright et al, 2016: 8). The GJMTC model ultimately collapses as a result of overspending by stronger councils to support a growing budget deficit of R300 million by 1998, with a R405 million overdraft and almost no capital expenditure (Cartwright & Marrengane, 2016: 8; Parnell, 2004: 383).

Johannesburg's fiscal crisis triggers provincial government intervention and a reorganization of the metro under a "One City, One Tax Base" rubric, which ultimately becomes a national model (Beall et al, 2002: 95). In 2000, after five years of the two-tier arrangement, a second consolidation process combines the separate MLCs into a single level "uni-city" under a new strategic vision, *iGoli 2002* (Mabin, 2006: 137). *iGoli 2002* is effectively a three-year transformation and development plan that targets fiscal, institutional as well as service delivery arrangements (Beall et al, 2002: 94; Parnell 2004: 383).

Ideologically, *iGoli 2002* is part of a wave of New Public Management (NPM) in South Africa. NPM and center-leftism ideologies have the support of global development institutions, such as the World Bank and the International Finance Corporation, which assist the ANC with political consolidation after apartheid (Pillay et al, 2006: 186; Bond, 1999: 43). NPM generally takes a neoliberal governance approach, including principles of efficiency and cost recovery (Pillay et al, 2006: 188). These principles are especially attractive for Johannesburg to address both its fiscal crisis and the persistent service delivery backlogs (Beall et al, 2002: 95; Tomlinson, 1999: 18; Bakker, 2003: 331), but many scholars view *iGoli 2002* as an imposition of neoliberal ideologies at the expense of participatory democracy and structural economic reform (Bond, 1999: 45, 2010: 10; Beall et al, 2002: 94-99; Parnell, 2004: 391; Barchiesi, 2007: 51; Winkler, 2009: 74l, 2011: 258). *iGoli 2002*'s slogan, "Johannesburg, a World Class African City", is seen to be a drive for economic growth at the expensive of redistribution (Todes, 2012: 162; Bremner, 2000: 191).

The *iGoli 2002* fiscal plan enables the City to generate a steady capital surplus or "cash reserves" for funding capital expenditure (CoJ, 2017/18: 11; Cartwright & Marrengane, 2016: 9). A robust cost-recovery agenda establishes a practice of resource-led budgeting, balancing in cash terms, not revenue, and firmer credit control (Beall et al, 2002: 93).[20] Cash reserves are important for municipalities that rely substantially on their own revenues (Van Ryneveld, 2006: 159). Provincial government relies on national government grants (or loans), and while some local governments do too, Johannesburg typically has one of lowest municipal dependency rates on loan transfers from national government. In its current model, the City's cash reserves hinge on raising funds from property taxes and charging for the use of services, such as electricity and water, the City's "trading services" (CoJ, 2017c: 13). It is also important to read the City's fiscal plans in light of the 1990s property boom, the decentralization of commercial development to the north of Johannesburg, and competition between the previously separate local authorities for economic investment (Todes, 2014: 86).

Cartwright and Marrengane (2016: 13) report that between 2006 and 2011, the City's capital budget rises to R3 billion, up from R295 million in 1999/2000. Revenue streams typically feed into operating accounts, which need to be in surplus so that funds are available for direct capital investment and for servicing loans and repaying bonds (Palmer et al, 2017: 19). The City's ability to borrow capital finance relates to the perception lenders have of available revenue in operating accounts (Palmer et al, 2015: 20).

iGoli 2002 establishes new institutional and fiscal contexts, and changes infrastructure governance. Corresponding to the NPM paradigm, the City devolves decision-making and restructures the delivery of local services into independent "business units"

[20] Johannesburg's fiscal problems also have roots in the approach of accrual budgeting, which credits income on future dues rather than receipt of payment, the under collection of revenue and the rates boycotts that lead to a growing level of debtors for services (Beall et al, 2002: 93).

(Barchiesi, 2011: 156) or Municipal Owned Entities (MOEs). These corporate agencies are responsible for basic services, including potable water and sanitation, electricity and waste management (Barchiesi, 2011: 156; Parnell, 2004: 389-390). In terms of the Companies Act (71 of 2008), MOEs operate as independent corporate entities, with the City as sole shareholder, having an oversight role, and thus they are essentially "State Owned Companies" (SOC) (PWC, 2012: 4).

Todes (2014: 87) reflects that the system is one wherein politicians are responsible for policy, but not site-level planning, other than decisions that contest policy. The implications of the institutional devolution are evident in Figure 5, which shows an organogram of City reporting line functions as at 2013, where MOEs operate as independent corporate entities reporting to municipal departments, which in turn operate within political portfolios under the executive mayor.

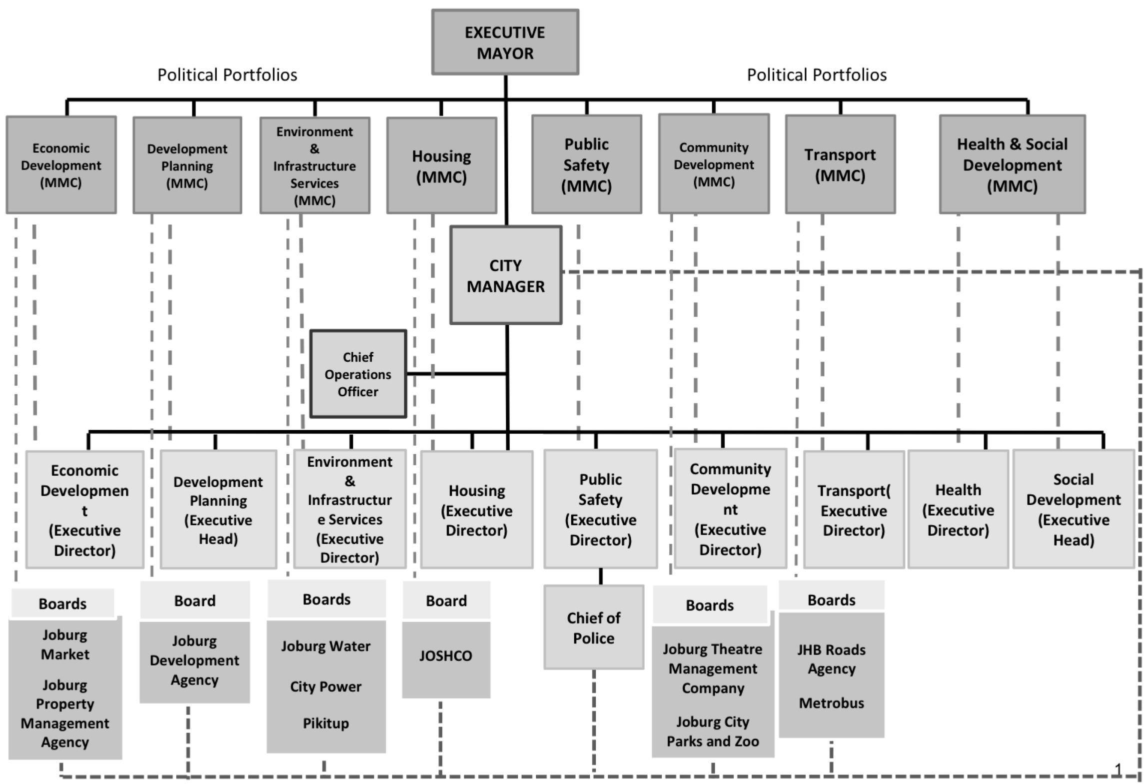


Figure 5 2013 Organogram of the City of Johannesburg (CoJ)

Line functions reporting to the City Manager, Municipal Entities and relevant political portfolios (CoJ 2013a). Reproduced with permission. Permission to reuse must be obtained from the rightsholder, the City of Johannesburg Municipality

Johannesburg's MOEs are contentious on several fronts. Several commentators reflect that the drive for efficiency, decentralization and corporatization results in the contracting out of public services, often without incorporating pro-poor tariffs or targeting policies (Harrison, 2006: 186-188; Binza, 2005: 84; Beall et al, 2002: 105).[21] A striking challenge in this regard is the Constitutional Court case, *Mazibuko v City of Johannesburg* (Dugard, 2008: 593), which centers around prepayment water meters in Phiri, Soweto. Prepayment meters are a cost recovery measure instituted by the City. Households have a Free Basic Water (FBW) allocation of 50 liters per person, per day, but once this has been exceeded, the meter automatically disconnects the water supply and additional water credit must be purchased (Dugard, 2008: 594, 603-605). The Constitutional Court significantly finds the installation of prepayment meters unconstitutional, on the grounds that the FBW supply is insufficient to meet basic needs, and the City's cost recovery method is unfairly discriminatory against historically poor black areas (Dugard, 2008: 594).

The Phiri water case represents the challenges of introducing a market logic into public resource management from a rights-based discourse (Bakker, 2007: 437). In Johannesburg, this plays out crudely in the post-1994 narrative, in light of the City being the sole MOE shareholder, while holding a developmental mandate, and at the same time ensuring cash reserves for infrastructure investment. However, there are fundamental complexities in the MOE model and infrastructure delivery context stemming from the managerially complex process of amalgamation. For example, JW experiences "teething problems" relating to sharing the functions of billing and meter reading, in a confusing governance context (Smith, 2006: iv). In the case of Johannesburg Roads Agency (JRA), responsible for roads and stormwater management, five separate pavement management systems, previously under the management of different consulting engineering companies, require amalgamation. These systems all differ in terms of:

- the source and accuracy of the centreline map;
- the spatial data completeness for higher level Geographical Information System analysis;
- the detail of pavement distress data collected;
- the level at which distress data is processed;
- the ability to provide consequence analysis given varying budget levels, etc.
(Olivier et al 1995)

Recent critiques of the amalgamation process point to tension between the MOE system and integrated planning, in terms of coordination and alignment (Todes, 2014: 86). There are recurring concerns about each MOE being responsible for a specific set of assets,

[21] Evidence also shows, however, that the tools of NPM are largely the regulation of the financial instruments for infrastructure expenditure (Savage, 2008: 287-288; RSA, PFMA, 1999).

with the result that the City experiences a form of "silo" management leading to a type of "separatist" prioritization and delivery of infrastructure in Johannesburg (Klein et al, 2012; CoJ, 2011a: 99).

As the City transitions into the post-1994 context and reorganizes itself institutionally as well as fiscally, it also confronts the major task of infrastructure "catch-up". This is a multi-layered challenge of extending infrastructure networks to those areas previously without, investing in new growth areas, and maintaining aging systems. These challenges exist in the context of mounting resource constraints, and concerns about climate change and the environmental externalities from economic activities, which fuels lively activism and critical reflection (Bond, 2007; Muller, 2007). South Africa's apartheid history means service delivery is intertwined with the transformation of racial inequality and the alleviation of poverty (Patel, 2000: 385; Pillay et al, 2006: 8), and is, consequently, subject to a strong developmental and rights-based discourse, as the neoliberal critiques of the MOEs show.

Academic research makes important contributions to the political, institutional and fiscal transitions of Johannesburg's post-1994 context. Scholars, such as Parnell (2004), Robinson (2003), Beall, Crankshaw and Parnell (2002), among others (see Pieterse, 2017), provide intricate analyses of Johannesburg's institutional reforms and long-term strategic visions. There is room to expand, however, on the specific infrastructure decision-making tools, databases and software systems used, which sometimes appear to lack either the narrative sophistication or appeal of critical urban analysis (Mosselson, 2017). A caveat is provided by research into the techno-politics of prepaid water meters (Von Schnitzler 2010, 2008) as well as reviews of the broad directions of strategic urban and spatial visions (Magni, 2013; Harrison et al, 2014; Cartwright & Marrengane, 2016; Pieterse, 2017). Yet largely missing from existing analysis is the standpoint from the City's infrastructure decisions, which often involve complex trade-offs between priorities.

5.3.2 Sustainability conundrums

The idea of sustainability conundrums or policy dilemmas facing the City in its infrastructure challenge builds on previous work by Götz and Schäffler in their critical reflection of a provincial sustainability strategy, the *Green Strategic Programme for Gauteng* (GSSP) (2011) (2015: 82). This work and the work of others (see Pieterse, 2017, Cartwright & Marrengane, 2016) highlights the importance of tying future theoretical and ideological scholarship to empirical understandings of infrastructure practice.

Tariff increases and rights discourses

The Phiri water case foregrounds the debates surrounding privatization in post-1994 South Africa in terms of rights-based activism and policy (Bakker, 2003; Bond & Dugard, 2008; Götz, 2018; Smith, 2006;). Metropolitan municipalities depend on their own revenue sources for infrastructure investment and, in Johannesburg, revenue from service charges for water and sanitation, as well as property taxes, are the main contributors to the City's capital budget (CoJ, 2017c: 123). The roots of this model lie in *iGoli 2002,* evident in an early contracting framework:

> - Utilities were established to manage the three major trading services, i.e. water and sanitation, electricity and refuse collection.
> - Agencies were established for those services such as parks and cemeteries and roads, which were funded from the rates accounts.
> - Corporatized entities were established for services that could attract user fees, such as the civic theatre, the zoo and the bus services. However, these services still required large subsidies from the rates account.
>
> (SALGA, 2011: 2)

One of the implications of this contracting model is that if usage declines, for example, through demand management initiatives, there are direct implications for the City's revenue generation. In August 2016, JW implements domestic consumer water restriction tariffs as a measures to curb excessive wastage. An upward scale is used, starting at 20 kiloliters, with the cost increasing as the usage increases (JW, 2016b). JW justifies the introduction of this measure as follows:

> South Africa is one of the thirtieth driest countries in the world. The country receives an average rainfall of less than 500 millimetres a year which is less than the world average of about 860 millimetres. This then means that South Africa can be considered a semi-arid country, receiving enough rain at times and sometimes not. Water supply in Gauteng is increasingly under pressure and the City of Johannesburg's water demand is continuously increasing in line with population and economic growth. This growth in demand cannot be sustained out of the Vaal Dam without any augmentation of the water supply into the Upper Vaal Catchment (JW 2016b).

It is useful to reflect on the annual tariff increases in the City's Medium-Term Budget (MTB), for trading services and property rates. Trading services are those for which tariffs are charged – electricity, water, sanitation and refuse (Palmer et al, 2017: 150). Table 1 shows that tariff hikes are the highest for water and sanitation, from a base year of 2016/18:

Table 1 Tariff increases for 2017/18 in the Medium Term Budget.

Service	Base Year 2016/17	Budget Year 2017/18	Budget Year +1 2018/19	Budget Year +2 2019/20
Property rates	5.90%	6.20%	5.90%	5.40%
Electricity	6.93%	2.28%	7.68%	7.69%
Water	13.20%	12.20%	8.90%	8.40%
Sanitation	13.90%	12.20%	8.90%	8.40%
Refuse	6.00%	6.20%	5.90%	5.40%

The higher adjustments for water and sanitation than for electricity partly reflect that national regulations allow flexibility in tariff-setting for these two services, whereas for electricity, South Africa's national energy regulatory controls prices (see Palmer et al, 2017: 150). For water and sanitation, the trend is also towards volume-based tariffs, implying higher volume consumers cross-subsidize low volume consumers, in line with government's agenda of free basic allowances, typically for the poor (Palmer et al, 2017: 181). The City's MTB provides more detail about tariff adjustments:

> Service charges – water and sewerage: Projected water and sewerage charges are estimated at R10.8 billion, approximately 21% increase from the 2016/17 financial year. The increase is based on an average tariff increase of 12.2%, based on a proposed Rand Water tariff increase of 10.2% plus a retail margin of 2%. Included in the revenue is an amount of approximately R320 million for the discontinuation of the 6 kl universal free basic water as from 1 July 2017 (limited to indigents only in future) and additional revenue of R280 million resulting from revenue initiatives introduced in the 2016/17 financial year (CoJ, 2017c: 13).

A former City official further reflects from the City's perspective:

> While the City's share of the increase always remains at inflation rate, the subsequent years are based on assumptions for what Rand Water Board will charge and JW always reflects a very optimistic picture for the future to please the political minds and soften the increase for the next financial year … JW always say, "Sorry, we have no choice to increase the tariff for the following year by so much, but we hope and pray it will be much less for subsequent years". This message softens the blow for the immediate increase based on the message that the future will hopefully be better (Ex-official, 2018).

These excerpts show the decision-making challenges facing the City in aligning infrastructure planning with service delivery objectives. The pressure to also appease political needs, particularly within a rights-based constitution and social discourse, sets up a tension between justice and sustainability imperatives (Götz, 2018). Tariff trends correspond to electoral cycles, and with national or general elections taking place in 2019 and local government elections due in 2021, the increases for water and sanitation get progressively less towards 2019/20, as can also be seen in Table 1. Eberhard reflects that strong municipal and political pressure to limit water tariff increases leads to a cost squeeze that ultimately translates into insufficient investment and under maintenance (n.d.). Utilities sometimes "frontload" investment, using an upward tariff adjustment to cater for a rapid increase in capital costs or compensate for supply uncertainties, such as climate variability (Jensen & Wu, 2017: 126).

There is an election anomaly in 2016 when the former opposition party, the Democratic Alliance (DA), wins the local government elections in Johannesburg and takes over politically. The link between political changeover and tariff hikes is evident in an earlier 2017/18 draft version of the *Medium-Term Budget,* which shows the tariff hikes initially proposed are higher than those council ultimately approves (Table 2). The City initially proposes tariff hikes of 13.9% for water and sanitation, which, while only a marginal percentage difference, is a significant difference in real terms for the consumer.

Table 2 Tariff increases for 2015/16 to 2018/19

Service	Base Year 2015/16	Budget Year 2016/17	Budget Year +1 2017/18	Budget Year +2 2018/19
Property rates	6.00%	5.90%	5.80%	5.80%
Electricity	12.09%	7.61%	7.93%	7.97%
Water	14.00%	13.90%	10.90%	10.60%
Sanitation	14.00%	13.90%	10.90%	10.60%
Refuse	8.00%	New tariff policy	8.20%	8.20%

(CoJ Draft Medium Term Budget, 2016c: 12). Reproduced with permission. Permission to reuse must be obtained from the rightsholder, the City of Johannesburg Municipality.

Johannesburg's municipal tariff context needs to be read in terms of the fiscal structure of trading services in South Africa. Volume-based tariff structures are key in raising revenue to offset the costs of provision and allocation of water services in a constitutionally mandated monopoly market (see Hollingworth et al, 2011). Volume-based tariffs imply that the price of services needs to rise to raise capital, and to reduce water consumption and inefficiency. But demand conservation affects revenue generation and the ability to fund future capital projects (Eberhard, 2018), and raises questions about where the various burdens should be placed (Götz, 2018).

The volume-based tariff system therefore presents the City with a structural conundrum of simultaneously effecting resource conservation, achieving development goals, and absorbing higher tariffs from its bulk supplier. The ongoing water crisis in the City of Cape Town (CoCT) graphically demonstrates the conundrum of the fiscal paradigm of volume-based water tariffs. In 2017, the mayor of Cape Town announces an impending "*Day Zero",* when the coastal city would be forced to cut off its main supply water as a result of the prolonged drought and inefficient demand patterns. The City subsequently undertakes a series of demand management initiatives as well as water augmentation schemes, such as agricultural diversion and desalination of sea water. It also provides for the water and sanitation department to increase its bulk water tariff and installs prepayment meters to restrict consumption and prevent wasteful practices (CoCT 2017, 23-28). The mayor is then forced to propose a drought charge, effectively a surcharge, to compensate for the revenue shortfall resulting from water saving measures, using the following rationale:

> People are using less water now and even though people are using less water, we still have to maintain and repair our reticulation system, and therefore money is needed (De Lille, 2018).

While volume-based tariffs enable municipalities to implement resource conservation tools, such as prepayment meters, the Phiri case highlights the need for a more nuanced approach to the right of access to sufficient water (Constitutional Court of South Africa, 2009. However, moving beyond ideological deadlocks and establishing a practical avenue for achieving equal and sustainable use of resources, also affects the City's ability to fund future capital expenditure. For the 2017/18 financial year, the City borrowed R3 billion (approximately $252 million at the time of writing) to fund future capital expenditure, partly as a result of a major revenue collection crisis, with revenue coming in at R3 billion lower than target (CoJ 2017c: 17). Loans contribute some 34.9% to the capital budget for the 2017/18 financial year, up from 27.5% in 2016/17 (CoJ, MTB 2017c: 96). The roots of the liquidity crisis lie in poor billing and collection practices. The City implements *Project Phakama,* for upgrading the functionality of billing, collections, metered services and other service options as well as payment schemes (FFC, 2012/13: 48; Mungoshi, 2010). Johannesburg's capital pressures reflect the more general situation in South Africa of municipalities and water boards, without sufficient capital, needing to raise debt finance, which in turn translates into higher tariffs (Palmer et al, 2017: 185).

While most consumers expect an inflationary increase in their annual tariffs, there is an ever-increasing basket of pressures, including rising demand, addressing apartheid backlogs and a growing maintenance crisis. Taken together, these pressures not only undermine the affordability of services, but also the City's ability to fund high-value projects and service high borrowing costs. Interest rates on the City's capital loans are projected to increase from 13.1% in 2017/18 to 13.3% for the following financial years (CoJ, 2017c: 100). The greater dependence on loans, and more expensive borrowing, reflects national fiscal pressure and low economic growth (FFC 2018/19). The City's capital pressures also indicate, however, the potential for alternative financing options. For instance, if the resources to invest in capital development are constrained or lacking, there is the potential for alternative financing options, such as development charges that leverage revenue from property owners and developers to fund future infrastructure connections (Berrisford et al, 2018).

Infrastructure is more complex than backlogs

As the chapter shows thus far, backlogs of basic service delivery are one of the legacies of apartheid and addressing them is the one of the key priorities for municipalities post-1994. However, identifying efficient locations of infrastructure connections presents a fundamental conundrum. The question of where to densify infrastructure is tackled in the City's *Corridors of Freedom* (CoF), a spatial vision promoting a high-density, mixed-use, transit-oriented development approach that steers future growth along specific corridors connecting to interchanges and urban transport nodes intended to connect people to economic opportunities (CoJ, 2013b: 2-4, 2017: 11). Key principles of this vision include efficiency, accessibility and sustainability, representing an important development in the thinking around creating sustainable human settlements (CoJ, 2013b: 2-4; Todes, 2012).

The corridors vision is significant for Johannesburg's "geography of poverty", where service inequities manifest spatially (Pienaar, 2016), and is a flagship initiative in its focus on density as well as linking strategic spatial planning and infrastructure prioritization (Todes, 2012: 158, 162; Pieterse, 2017: 3).

Within the corridors vision, the City faces a challenge in the growth housing for the urban poor in or close to existing African "townships", while simultaneously addressing the historically distorted patterns of infrastructure investment and growth (Biermann, 2000: 295; Todes, 2012: 159). These perversities derive not only from the legacies of apartheid spatial planning but also from the City's first amalgamation process, during which, Bremner argues, there is failure of political will to access the funds and technical capacities for a *Rapid Land Development Programme* (RLDP) (2000: 98).

Transit-oriented and high-density visions face cost and logistical challenges from infrastructure capacity, demand, location and density over time as well as space, in servicing outlying growth areas (Biermann, 2000: 295). For some peripheral areas, the per capita costs of bulk infrastructure connections are high, compared to investing in areas closer to mainline connections, potable supply, purification works and waste dispose networks (Biermann, 2000: 295; Klein et al, 2012: 21). Nevertheless, the City's "deprivation area" program focuses on investment housing, bulk water provision, sewer infrastructure, electricity infrastructure, and road building, in upgrading informal settlements and marginalized areas, such as Orange Farm (CoJ, 2017d: 165, 176). In this way, the program aims at overcoming the spatial inefficiencies and service inequities of apartheid, which manifest in Johannesburg's geography (Pienaar, 2016).

The challenges of where to density efficiently are partly political, and the CoF encounters a number of political disjunctures. For instance, recent political commitments direct significant resources for infrastructural development and improving access to services to Soweto and other former township areas, where growth traditionally outstrips available infrastructure (Todes, 2012: 164, 2014: 89). Yet, provincial government's "mega-human settlement" drive prioritizes housing investment away from the urban core because of the relatively low costs of land there (GPGHS, 2017), and so several "private-sector-led mega human settlements" are underway in areas, such as Lanseria, which border Johannesburg (Makhura, 2015, 2017: 4). While these are important from a housing provision perspective, they represent a real-estate model that contrasts markedly with the City's corridors vision. In addition, the provision of low-cost housing on the urban periphery requires major new infrastructure investment and encourages sprawl that challenges the City's ability to realize infrastructure efficiencies (Klein et al, 2012: 61-62). The provincial government's reliance on the private sector to steer development is also politically tenuous in light of research indicating that private developers often neglect the very low-income brackets in their social housing initiatives (Ballard et al, 2017: 126).

CoF's longevity may be affected by political change in Johannesburg, but at the time of writing, it has the formal support of the DA administration with respect to compact development, although there are questions about levels of support and policy interpretation (see Ballard et al, 2017: 126).

The deferred maintenance crisis

Like many rapidly growing cities, the infrastructure network that serves Johannesburg is not only much smaller than the City needs, but also requires significant upgrading and repair. In high-density areas such as the inner city, solid waste infrastructure struggles to keep pace with a growing number of people and the proliferation of informal businesses. Waste dumped in the streets clogs culverts, causing sewer and stormwater system malfunction, and leading to contamination downstream (OECD, 2011: 65). Equally sinister is the leakage of raw sewerage, resulting from blocked pipes and failed upgrades, into the Jukskei River, triggering concern about hazardous biological waste causing eutrophication (Kings, 2016). The breakdown of wastewater systems prompts an investigation by engineers of new models for increasing the capacity of Northern Wastewater Treatment Works, the City's largest treatment facility (Naidoo, 2017).

There is also the issue of Johannesburg's Unaccounted-For Water (UAF) or water that is lost through leaks in the reticulation system, and unrecorded, unbilled consumption (CoJ, 2011: 56). While official statements differ, and despite some maintenance improvements taking effect, a 2017/18 report estimates these levels at around 32% (JW, 2017c: 43).

These examples reflect a wider crisis of "deferred maintenance", defined by the national Department of Public Works (DPW) as the portion of planned maintenance work necessary to maintain the service of an asset, but that has not been undertaken in the period in which such work was scheduled (RSA DPW, n.d: 10). If the share of maintenance expenditure as a proportion of total expenditure is low, while municipal asset bases grow with new capital investments, municipalities experience a delay, or even some suspension, in seeing to maintenance needs (RSA, 2008: 31). Deferred maintenance typically results in a mounting renewals backlog, which impacts negatively on the reliability and quality of services, and ultimately on the financial sustainability of municipalities as well (RSA, 2011: 7).

To address the issue of deferred maintenance, the South African National Treasury provides guidelines for maintenance and repairs of 8% as a percentage of property, plant and equipment (PPE) applying to bulk infrastructure assets (CoJ 2017c: 38).[22] The PPE ratio is a function of the replacement value multiplied by remaining useful life (DPLG, n.d). Circular 55 of the Municipal Financial Management Act (MFMA) also stipulates that asset renewal must constitute at least 40% of municipal capital budgets (RSA, 2011: 7). For the 2017/18 financial year, the City meets the capital budget allocation to

[22] Property, plant and equipment (PPE) are tangible items that: (a) are held for use in the production or supply of goods or services, for rental to others, or for administrative purposes; and (b) are expected to be used during more than one reporting period (FFC & SALGA, 2014/15: K).

maintenance of 40%, but fails to meet the 8% PEE stipulation over the medium term ending in 2019/20 (CoJ, 2017c: 38). The City achieves a PPE ratio of 7.2% in 2016/17, up from 6% in the previous year, but this drops to 6.1% in 2017, 2018 and 2019 (CoJ, 2017c: 16). While these figures are about 10% higher than similar municipalities, the greater capital allocation to maintenance indicates how previous maintenance deferrals subject the City's budget in future cost pressures. Evidence for the City's expenditure breakdown derives from the *Sustainable Services Cluster,* which, at the time of writing, is the political portfolio for the Department of Environment and Infrastructure, Housing, City Power, Johannesburg Water, and Pikitup (solid waste removal), among other key City service delivery agents. In 2017/18, the expenditure budget for Johannesburg Water (JW) increases from the previous financial year by 12.9 %, to R9.6 billion, in addition to the increase in bulk purchases, due to repairs and maintenance (CoJ 2017c: 123-125).

Figure 6 presents information from the *2017/18 Medium Term Budget* indicating the City's strategy of addressing maintenance backlogs, and shows that from a budgetary stance, at least, there is an intention to close the gap of depreciation in relation to repairs and maintenance.

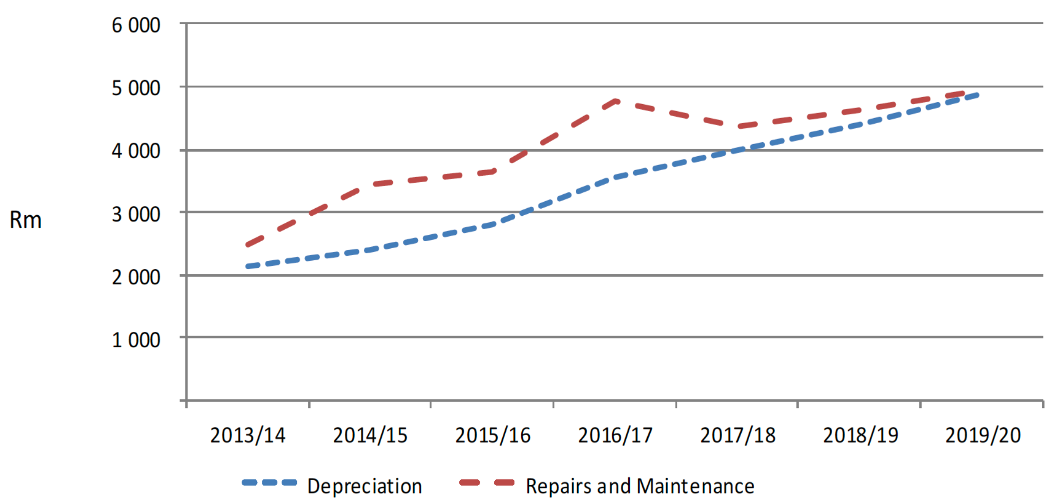


Figure 6 Depreciation in relation to repairs and maintenance over the medium term (CoJ 2017c: 28). Reproduced with permission. Permission to reuse must be obtained from the rightsholder, the City of Johannesburg Municipality

While models can measure the pace of infrastructure deterioration with regard to the expected useful life of infrastructure to inform planning, in practice the assets are "pushed to the limit" in severely constrained capital budgets and with stretched maintenance capacity (FFC, 2014/15: 135). In addition, there are doubts about the extent to which the National Treasury's PPE ratio truly reflects the physical pressures on infrastructure and if meeting it is sufficient to close the gap between depreciation and maintenance needs. The FFC, for instance, argues that there are inherent flaws in the PPE calculation, particularly for non-revenue generating infrastructure such as libraries, but also for trading services, such as water, that have limited cost recovery due to the large capital requirements of facilities such as wastewater purification works (2014/15: 138).

More fundamentally, the 8% treasury allocation is likely insufficient to cover the wider basket of needs that include upgrading current infrastructure while addressing backlogs of previous deferred maintenance (Ncube, 2018). Following an interview with the Local Government Unit of the FFC, Mkhululi Ncube, reflects further that the 8% figure has a further flaw in that the PPE ratio is a function of budget affordability, not a function of asset needs or change, such as physical pressures from climate change (Ncube, 2018; also see FFC, 2014/15: 138). The FFC also finds no comparative PPE figure in international infrastructure management literature, raising concern about whether the City's maintenance plans encompass the full scope of infrastructure asset management, in terms of global best practice (FFC, 2012/3: 2).

The City is investing in new infrastructure, but deferred maintenance remains a major part of the investment challenge. The growing reliance on loans reflects the need to direct a higher proportion of the capital budget to maintenance, as the allocations from the *Sustainable Services Cluster* indicate. While Johannesburg is an anomaly because of its relatively robust ability borrow, in contrast to smaller municipalities that rely on transfers from national government, this implies a higher proportion of its capital budget is directed to covering maintenance issues that are traditionally operating expenditure. In Table 3, an excerpt from the City's draft capital expenditure budget for 2018/19 shows not only the share of capital spending on "new" infrastructure, but also that upgrading, and renewal, are becoming capital budget issues.

Table 3 Draft capital expenditure budget 2018/19

Municipal Standard Chart of Accounts Project Segment of the Draft 2018/19 Capex Budget	2018/19	2019/20	2020/21
New infrastructure percentage	56%	51%	58%
Upgrading of infrastructure percentage	25%	26%	18%
Renewal of infrastructure percentage	18%	22%	23%

(CoJ 2018b). Reproduced with permission Permission to reuse must be obtained from the rightsholder, the City of Johannesburg Municipality.

5.4 The rise of infrastructure prioritization tools

During his 2011–2015 term, the mayor Parks Tau, the City undertakes a review of its growth management and development direction. A strategic process, the *Growth and Development Strategy* (GDS)*,* replacing the earlier *Joburg 2030* plan, provides the new long-term development vision linking infrastructure implementation to spatial planning (Todes, 2012: 162).

In 2006, the City Council approves the GDS together with the *Integrated Development Plan* (IDP)*,* which South African municipalities formulate every five years to plan their overall priorities and development directions (Pillay et al, 2006: 15). IDPs include a framework for sector plans, budgets and main programs, and capital projects for the future municipal cycle (Todes, 2012: 162). The spatial focus of the 2006 GDS and IDP is part of a wider infrastructural turn within spatial planning that addresses critiques of the IDP as no more than a "public management tool" (see Watson, 2002: 85). The GDS evolves into another high-level planning process, the 2008 *Growth Management Strategy* (GMS).

In the early 2000s, a commercial property boom in Johannesburg results in large-scale flight from traditional business centers, such as the inner city, and a growth in retail, industry and office space along mobility routes (CoJ, 2008b; Ahmed & Pienaar, 2014: 106). There is also a growth in low-density housing developments, both "new townships" on the urban fringe and enclaves of medium-to-high income development, particularly in the Northern suburbs, which challenge the City's ability to provide efficient and integrated infrastructure (Ahmed & Pienaar, 2014: 104). The City engages with "growth management" as a way of managing the challenging pattern of sprawl and car-dependency (Götz, 2017). The concept of growth management offers the municipality a narrative for understanding and translating the impact of development on infrastructure capacity:

> Growth management is an approach that is now widely used internationally to ensure that growth in population and the economy is supported by the necessary services and infrastructure and at the same time meets spatial and socio-economic objectives (CoJ, 2008b).

The GMS plays a formative role in the City's analysis and monitoring of spatial change, although the philosophy is not without its challenges (see Pieterse, 2017a). A presentation of the GMS during the 2008 *Budget Lekgotla*[23] includes a series of spatial analyses of growth pressures likely to impact on infrastructure capacity (see Figure 7). These analyses demonstrate an effort by the City to formulate a strategic diagnostic for assessing bulk infrastructure in terms of demand and investment requirements, and ranking critical projects according to high, medium and low priority areas for the allocation of resources (CoJ 2012a: 21).

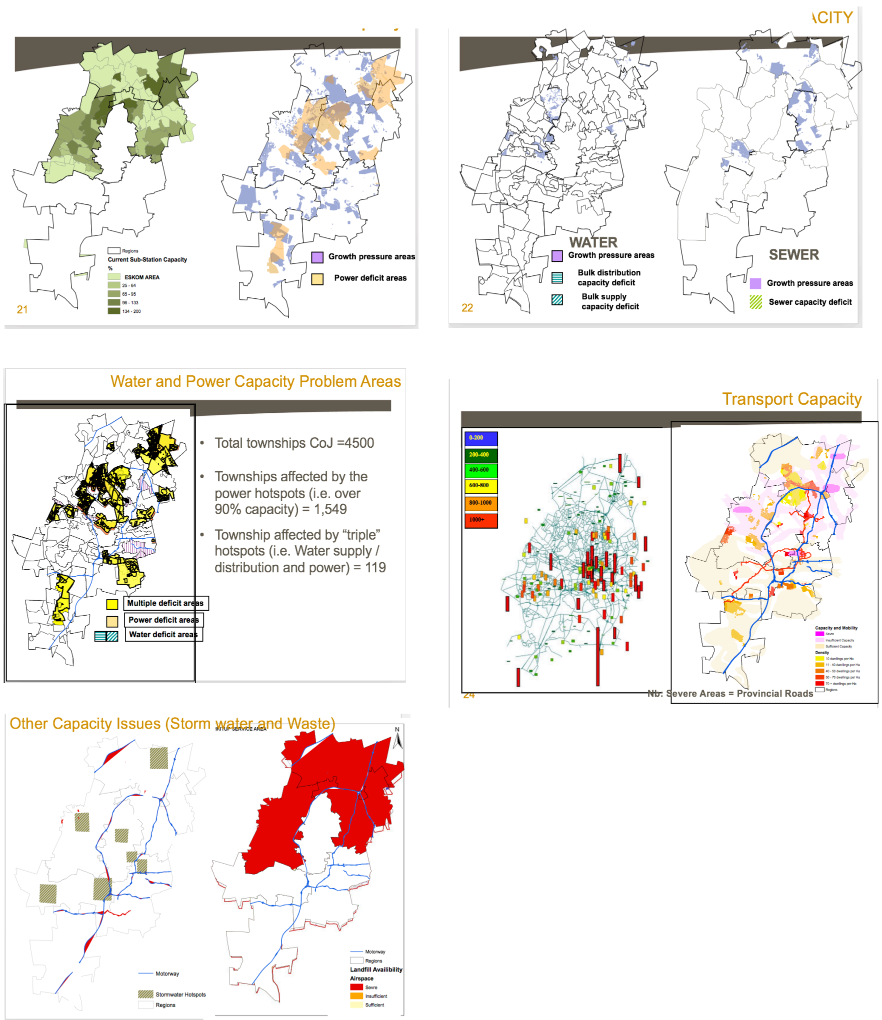
The GMS diagnostic overlays infrastructure capacity and growth pressure areas in the City for the purposes of: a) maintaining existing infrastructure, b) prioritizing deficit areas and c) directing future investment. These issues are central to how the GMS is intended to evolve as an investment footprint strategy that prescribes the location and conditions for accommodating growth (CoJ, 2012a: 21; CoJ, 2014b: 97) and dealing with "bottlenecks" or "hotspots", where systems deficits and backlogs overlap with growth pressure areas to undermine growth targets (Ahmed, 2018).[24] Figure 7 shows spatial rendering outputs for the City using the growth management idea to interpret its investment footprint according to areas of "growth pressure" and "infrastructure deficit" for critical infrastructure projects (CoJ, 2008b).

The question of how to prioritize infrastructure investment also has roots in the set of infrastructure and spatial coordination processes leading towards *iGoli 2002.* During the early 2000s, the City's *Spatial Development Framework* (SDF) defines its spatial vision and means of implementation (Todes, 2012: 16; CoJ, 2012B). SDFs are statutory requirements within the IDP that include a hierarchy of local level plans, such as regional spatial development frameworks, urban development frameworks and precinct plans (Magni, 2013: 5; Ahmed & Pienaar, 2014). In South Africa, the SDF process is also a

[23] *Lekgotla* is a Sotho word referring to a gathering. In the context of government, a lekgotla is a strategic planning meeting where budget and planning issues are discussed (OECD, 2006: 15).
[24] In terms of future investment, the City's interpretation of "growth pressure areas" reflects the stance of Mayor Parks Tau for directing development in the "right locations" or "opportunity areas", versus an anti-growth philosophy (Götz, 2017).

response to the era of “master planning”, when the failure to consider spatial location and capital requirements not only undermines infrastructure suitability, but also accentuates race and class distortions (Klein et al, 2012: 23).

Figure 7 City diagnostics from the Consolidated Growth Management Strategy



The diagnostics show capacity issues using the infrastructure bottlenecks/hotspots narrative (CoJ 2012c: 89). Reproduced with permission. Permission to reuse must be obtained from the rightsholder, the City of Johannesburg Municipality

Johannesburg's SDF is significant in establishing principles relating to sustainability, efficiency and accessibility of the urban environment in spatial planning (CoJ, SDF, 2012b). These principles are part of a spatial transformation agenda of investing in nodal points, previously disadvantages areas, and emerging transportation routes, such as the new Bus Rapid Transit (BRT) system, as development corridors (CoJ, 2012c: 22). Studies track how these planning narratives are fundamental components of the changing spatial environment of the City, particularly after the rise of the Corridors of Freedom (CoF) vision of transit-oriented and mixed-use development (Todes, 2012; Harrison et al, 2014).

However, prior to GMS and SDF, a lesser-known process unfolds as a technical experiment by the City to support infrastructure planning. During the late 1990s, the City manager pilots a system for prioritizing infrastructure investment for the Midrand Transitional Local Council (MTLC) (Magni 2013: 5, 2017). [25] The system is essentially a Microsoft Excel spreadsheet that determines and prioritizes the MLTC's infrastructure need in terms of the City's changing spatial imperatives (Magni, 2013: 5).

However, at the time of the MTLC initiative, the idea for a capital investment decision tool is already underway at the Johannesburg Roads Agency (JRA), which approaches engineering firm, Karabo Consulting, to assist with post-1994 infrastructure amalgamation and develop a method for prioritizing capital projects. JRA's version of the spreadsheet was a planning list of capital projects, but without the data requirements necessary for decision prioritization. Developing a method for assessing multi-year capital budgets, funding sources, spatial locations, implementing agent and other prioritization factors was therefore a key outcome of the JRA–Karabo initiative (Scheepers, 2108).

After the JRA work, the City approaches Karabo Consulting for a similar, city-wide capital investment prioritization platform (Scheepers, 2018; Viljoen, 2018). A former City official elaborates:

> In the case of the CoJ, our financial standing and credibility was such that we could generate approximately R10 billion in capex funding for purposes of investing into assets. The consolidated register then created an opportunity to prioritize projects. As an example, there were in excess of 6 000 projects at any point of time, due to backlogs and future needs, with capex requirements beyond R100 billion. So the City needed a "prioritization model" that would assist the City in taking decisions about which projects to fund and which ones not. This prioritization model was based on spatial and political objectives (2018).

---

[25] Midrand in the central Gauteng Province.

In response, Karabo determines that a city-wide capital prioritization method requires both engineering capacity as well as software development and establishes an additional business vehicle, iSouth for this dual purpose (Scheepers, 2018). Following the *iGoli 2002* process, the prioritization method is the decision support tool, *Capital Investment Management System* (CIMS). Together with the development paradigms of GDS and SDF, CIMS unfolds with the Capital Investment Framework (CIF), in accordance with Section 26(i) of the Municipal Systems Act (Act 32 of 2000) that requires local government to present a three year-financial plan of capital budget information (CoJ, 2013/14: 180). These city vision processes, as well as CIF at a national level, are evident in how CIMS develops as:

- A single database for investment programs and associated capital needs;
- A prioritization tool/reporting module on specific scenarios and project management/tracking;
- A platform for the City to understand the city-wide implications of investment decisions;
- A system yielding spatial information
- A prioritization hierarchy for the location of capital investment;
- A system for project reporting and tracking, yielding spatially referenced information on the city-wide implications of investment.

(CoJ, 2006: 128).

Figure 8 shows an early conceptual framework of CIMS within the capital budgeting process and some of the evolving priorities that feed into the project hierarchy process. From a planning perspective, CIMS occupies an important, yet subtle role in the evolving infrastructure planning context of the City. CIMS software is the first tool used by the City that spatially references demand and capacity pressures, alongside the capital budget (Magni, 2013: 1-5). In addition, the software is a first attempt at multi-criteria decision analysis (MCA) for prioritizing different political, financial, environmental and technical needs in relation to infrastructure. The intention is to make CIMS accessible to all City service providers via the internet and internal information platforms (CoJ, 2006: 128).

However, CIMS faces challenges to its functionality and longevity. A former official in the Department of Infrastructure Management, City Transformation and Development Planning reflects:

> The project list is only as good as the information captured on CIMS by the departments. If this information is not correctly captured, this is the information that appears in the budget.
>
> There is a tendency for departments and MOEs to redirect funding from projects in the budget that are located in strategic areas to other projects during the budget adjustment period. This is in the absence of effective administrative oversight during the adjustment budget process.

There is no means of verifying whether the CAPEX spend was spent on what was budgeted, and whether the infrastructure provided was of sufficient quality. The lack of an effective monitoring system is a major concern.

The prioritization model used on CIMS is complex. This makes it difficult to communicate to departments and MOEs why one project is prioritized over another.

(Magni, 2013: 7).

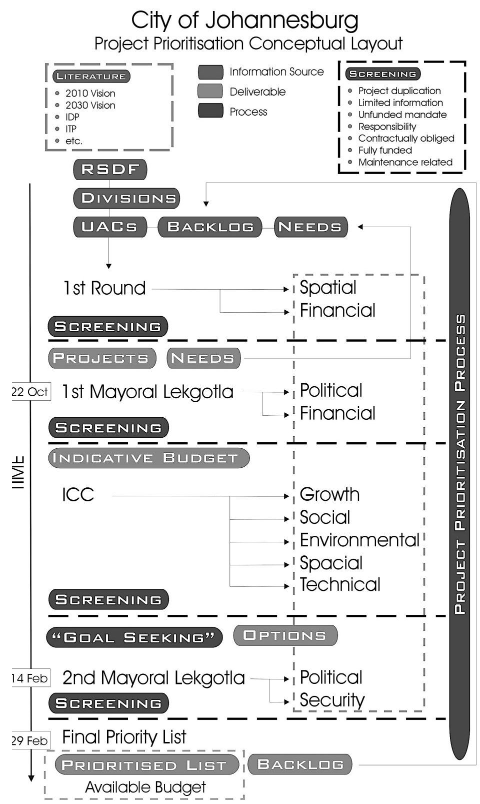


Figure 8 NOVUS^3 concept framework
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Magni argues that CIMS is only as effective as the supporting data, and technical and institutional capacity that exists within the software/engineering "collaborative" (2013: 6). Another former official reflects that the "engine room" of technical support, which relies on contract employees from the City and the consulting firms, causes a later "hollowing out" of infrastructure modelling capacity (Götz, 2017). A former director of the Environment and Infrastructure Services Department (EISD) notes that because the software underlying CIMS requires the payment of license fees, the City considers switching to an equivalent program that is available for free (Ehlers, 2018). There are, however, opposing views about the notion of such "freely" available software since market-related software with the equivalent functionality of CIMS requires license, support and maintenance fees to be paid (Scheepers, 2018).

At some stage after the 2013/14 IDP, there is a lapse in the contract between the City and iSouth, so that the CIMS software is only supported from a software and maintenance perspective (Scheepers, 2018) and the functionality of CIMS fails to keep track of planning and budget reforms in the South African development context. This may partly explain the hollowing out of technical capacity behind CIMS. In addition, iSouth stops trading around 2007, after which the City contracts Gendec, a software development company to support CIMS from a technical maintenance perspective (Scheepers, 2018). As a result, CIMS in Johannesburg has no functionality improvements to support decision workflow, such as updates in accordance with spatial planning and budgeting reforms from National Treasury in 2007.

In 2014, the City approaches the architects of CIMS to update the infrastructure decision tool and revise the underlying methods (Scheepers, 2018). Although iSouth no longer exists, the CIMS architects are part of a new infrastructure planning and engineering consultancy, NOVUS^3, which, during the contractual lapse, undertakes software revisions that become a *Capital Planning and Periodization Platform* called CP^3. The City of Tshwane (formerly Pretoria) rolls out an early version of the CP^3 system, which is later rebranded as the *Capital Planning System* (CAPS) in 2013, and adopted by the City of Ekurhuleni and Stellenbosch Municipality in 2016 (Viljoen, 2018).

The reboot of the earlier CIMS happens under the name *Johannesburg Strategic Infrastructure Platform* (JSIP), using the newer CP^3 functionality (NOVUS^3, 2018). Although much of the earlier decision logic remains the same, CP^3 revises the functional sophistication and underlying software technologies of CIMS, allowing alignment with the wider planning and fiscal reforms. The updates culminate in a four-module centralized decision-support system that captures, prioritizes, budget-tracks and reports on an extensive set of criteria for infrastructure. While most MCA deal with quantitative and qualitative criteria, the updated CP[3] approach also has a critical spatial dimension that creates a spatially-enabled MCA prioritization tool, which, according to NOVUS[3], is not widely implemented internationally (Scheepers, 2018).

Under the new JSIP brand, the updated MCA allows the City to simulate infrastructure alternatives and debate outcomes, such as different mayoral priorities and the location of investment impacts (NOVUS[3], 2018). There are also a number of functional "extras", such as dynamic socio-economic models for simulating infrastructure investment employment contributions, spatially referencing weighted community service needs or assessing fiscal ratios (NOVUS [3], 2018).

The CP[3] developers argue that JSIP benefits from the software developments and workflow improvements that occur during the earlier contract lapse (Scheepers, 2018). However, the reincarnation of CIMS happens as another City process unfolds, the *Consolidated Infrastructure Plan* (CIP). The co-evolution of JSIP and CIP not only provides a critical link between the City's efforts to improve decision capacity, but also signals a historically significant shift towards integrated planning in establishing the enabling environment for sustainability decisions.

5.4.1 The rise of CIP

In 2013, the City launches CIP as a multiyear process for consolidating and integrating the planning, implementation and management of infrastructure (Aurecon, 2014b). It is part of an initiative by the City's Environment and Infrastructure Services Department (EISD) to quantify infrastructure needs (Pillay, 2015). EISD outsources the development and management of CIP to international management consultant, Aurecon.

The first phase of CIP provides a cash-flow forecast of Johannesburg's bulk infrastructure requirements using a baseline Socio-Economic Model (SEM).[26] This model indicates that over ten years, the City's infrastructure needs are in excess of R100 billion[27] for addressing service and maintenance backlogs as well as enabling future development. The "R100 billion" figure gains momentum as a planning narrative (Pillay, 2015) and brings into focus questions about both the sustainability of Johannesburg's urban form and the capacity of decision-making tools for future infrastructure investments. The key consultant engaging with the City, explains:

[26] The financial modelling efforts include simulating future development trends according to the Sustainable Human Settlements Urbanization Plan (SHSUP), bulk capital projects for all sectors over twenty years and assessing the status of infrastructure in terms of refurbish needs (Aurecon, 2014).
[27] Approximately $ 8 billion at the time of writing.

> New investment is the biggest 'thumb suck' because of future growth projects, which will likely exceed current capacities by a large degree, while existing data about infrastructure is either inconsistent or incomplete (Van den Berg, 2016).

According to Van den Berg, the data and asset registers of MOEs are a major issue for the City since they have major discrepancies that undermine financial alignment, but they also show that infrastructure needs are potentially more critical than anticipated (2016). The Assistant Director of Infrastructure Planning and Coordination agrees:

> The historical approach to infrastructure planning is to plan in isolation, i.e. the various Municipal Owned Entities (MoEs) plan separately and do so based on "thumbsucks" The Department of Environment and Infrastructure Services views the CIP process as an attempt to instigate reporting of the main infrastructure portfolios to report to 'Infrastructure' via what is essentially a funding model of how the R100 billion should be spent (Pillay, 2016).

The focus of CIP is the bulk infrastructure that the City views as fundamental to urban services: roads and stormwater; water and sanitation; solid waste; and electricity. These four infrastructure portfolios operate under the MOEs that report to the City. JRA manages roads and stormwater, and reports to the City's Department of Transport, while the MoEs for water and sanitation, solid waste and electricity all report to the Department of Environment and Infrastructure Services, via Johannesburg Water, Pikitup, and City Power, respectively (CoJ, 2017f; CoJ, 2014b: 24).

As separate entities, each of the MoEs use different systems and data sets, creating coordination challenges across the board. Van den Berg argues that JW is the most advanced entity, using asset management software called IMQS, while City Power uses SAP, JRA owns and manages its own asset register, and Pikitup has no asset system at all (2016). While CIP emerges in relation to the "doomsday" figure of R100 billion, it is also in response to strengthening coordination planning and asset management approaches between the MOEs, in order to provide a more credible long-term understanding of infrastructure capital demands. This is evident in Box 2, which shows the project objectives of phase one of CIP taking place between March and June 2013.

Box 2 also shows that in 2014, the CIP is a critical link in the City's interpretation of the previous CIMS. Later iterations carry forward the ideas of standardized planning while refining the earlier SEMs in accordance with the City's evolving planning environment. Historically, the CIP is significant as the first high-level infrastructure asset management process in the City that coordinates the needs of the respective infrastructure agencies (the MOEs) in terms of future capacity and maintenance of existing assets, and does so according to spatial prioritization. The CIP process formally establishes the practice of Infrastructure Asset Management (IAM) in the City as "[investing] in existing infrastructure assets to address asset life cycle requirements. It includes refurbishment and replacement in order to secure continued service delivery" (CoJ, 2017a: 162). Life-cycle asset management is intended to enable the City to assess both capital expenditure and operating requirements over time to balance investments (Pillay, 2016).

- Superimposing future development trends in the form of population, economic and land use growth projections according to the Sustainable Human Settlements Urbanisation Plan (SHSUP).
- Identifying the envisaged bulk capital projects required for each of the relevant sectors according to the projected growth projections over a 20-year period.
- Defining the status of the current infrastructure information, which is based on the current level of available information and indicating the refurbishment needs of each of the relevant sectors over a 20-year period.
- Developing a User Requirement Specification (URS) for the Consolidated Infrastructure Management System (CIMS) for additional requirements which the current system lacks.
- Assessing the institutional capacity of the Municipal Owned Entities (MOEs) and the CoJ's Environment and Infrastructure Services Department (EISD).
- Defining a programme management facility to monitor, report and coordinate the City's infrastructure delivery.
- Developing an infrastructure investment optimization strategy to realize a cost saving in the refurbishment projects which overlap the capital projects.

Box 2 Consolidated Infrastructure Plan (CIP) project deliverables (Aurecon, 2014b)

Importantly, the CIP is unfolds together with the City's SDF, which is key to the spatial perspective of capital investment for infrastructure investment (Aurecon, 2015a). SEM refinements include alignment with the CoF, as well as growth projections and how to coordinate these with the City's emerging spatial vision. Critically, these spatial perspectives exist along with, and are enabled by, the JSIP, which allows the City to adopt a dynamic, spatially referenced multi-criteria understanding of infrastructure investment. The JSIP is important as CIP's underlying decision support tool (Aurecon, 2015b). At the same time, the CIP process and its institutional momentum provides an essential link to, and reinvigoration of, the earlier CIMS. In addition to the contractual lapse mentioned earlier, there is another lull in the planning process of about ten months ending in December 2017, after which the City makes progress with the JSIP process (Scheepers, 2018). The lull corresponds to the DA political changeover and an institutional review (a council requirement for new political leadership), that calls for the MOEs to be incorporating back into the City administration.[28]

The JSIP does finally re-emerge and, following council approval in the 2017/18 political cycle, becomes the "capital investment prioritization model" across key strategic documents (CoJ, 2018a: 55). With its spatial perspective, JSIP is particularly useful for the City's evolving interest in the SDF:

> Importantly, along with providing a spatial vision, the SDF defines the strategic spatial areas to be used in the City's capital investment prioritisation model (Johannesburg Strategic Infrastructure Platform – JSIP). This will ensure that infrastructure investment is directed to areas with the highest potential to positively impact on the development trajectory of the city as defined in the SDF (CoJ, 2018a: 119).

JSIP is the key enabler of the City's Capital Investment Priority Areas (CIPA) concept, which forms the basis of its transformative spatial vision of transit-oriented development (CoJ, 2016a: 24).[29] Pieterse (2017) argues that the CIPAs are significant in showing refinement of the earlier GMS ideas about strategic growth in priority transformation areas according to mixed use, transit-oriented development (CoJ, 2016/7: 24; Pieterse, 2017: 10). Figurs 9, 10 and 11 shows these refinements in the spatial outputs of the Built Environment Performance Plan (BEPP) and the carry-over of the earlier narratives including infrastructure bottlenecks or hotspots, deprivation areas and service backlogs in marginalized areas (CoJ, 2017d: 19-20).

[28] This institutional review subsequently faces a motion of no confidence following tender irregularities (see Mailovich, 2017).
[29] The CIPAs shift in the direction of Spatially Targeted Areas (STA), in line with the National Treasury narrative of the Built Environment Performance guidelines.

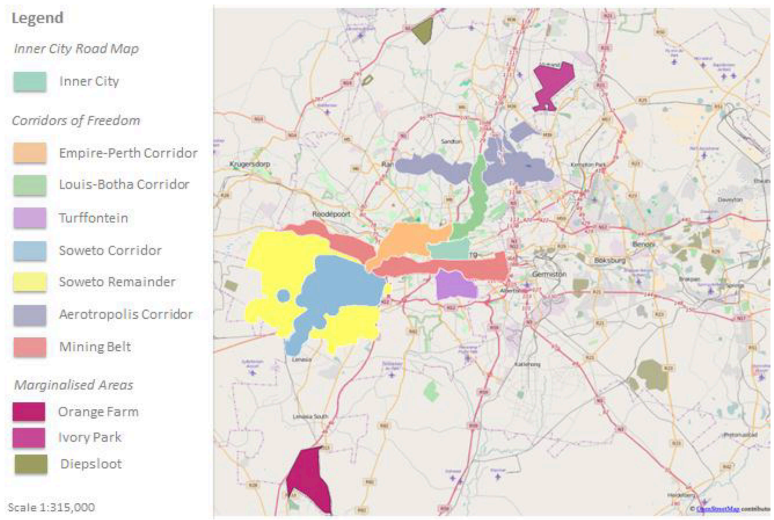

Figure 9 Capital Investment Priority Areas (CIPAs) The CIPAs derive from the "Priority Transformation Area" narrative about strategic growth areas (CoJ, 2017d: 21). Reproduced with permission. Permission to reuse must be obtained from the rightsholder, the City of Johannesburg Municipality

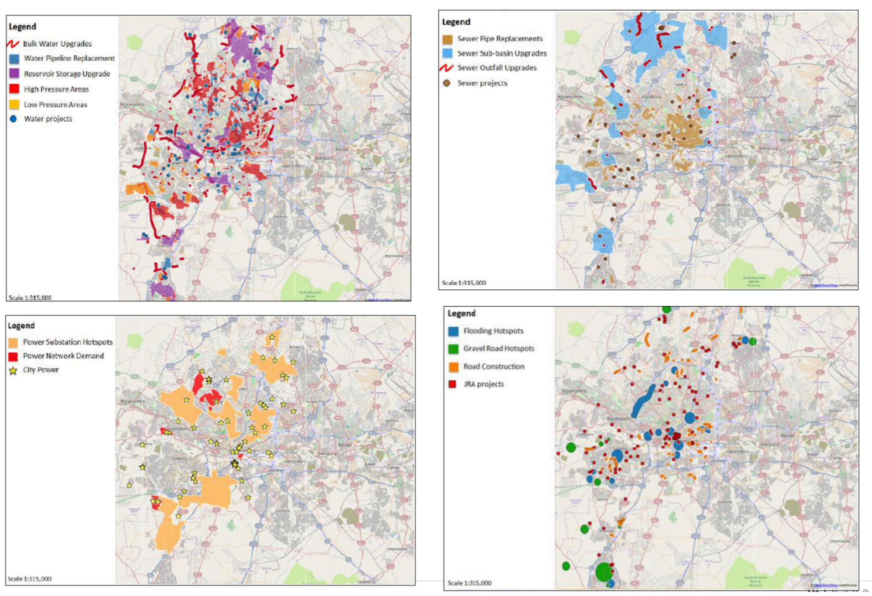

Figure 10 Infrastructure hotspots for water, sewers, power and roads. (CoJ, 2017d: 19). Reproduced with permission. Permission to reuse must be obtained from the rightsholder, the City of Johannesburg Municipality

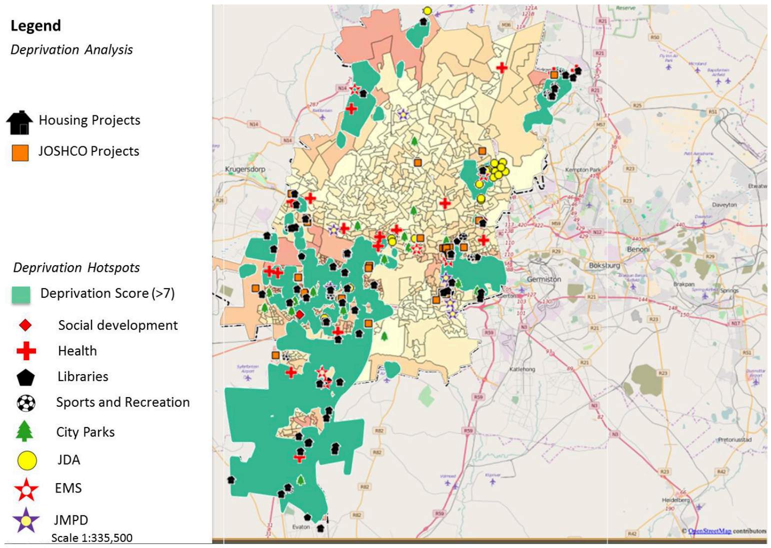

Figure 11 Investment related to Marginal or Deprivation Areas (CoJ, 2017d: 20). Reproduced with permission. Permission to reuse must be obtained from the rightsholder, the City of Johannesburg Municipality

While Pieterse argues that the "fascinating" CIMS software underpins the CIPAs (2017: 10), there are nuances to the underlying decision support systems. While CIMS aimed to analyze multiple criteria, it is the CP^3 software that allows the City to conduct multi-varirate spatial and temporal analysis. In addition, the consultants working on CIP emphasize that Johannesburg's "enabling infrastructure" (Aurecon, 2014a) hinges on both the JSIP, which deals with all capital and operating expenditure according to the Medium Term Expenditure Framework (MTEF), and its evolution from CIMS (Van den Berg, 2017). While the CIP deals with bulk engineering infrastructure (water, sanitation, roads, stormwater, electricity and solid waste) over a 10-year period, the JSIP is concerned with the costs and functions of infrastructure expenditure. In this sense, JSIP is the underlying prioritization tool that categorizes projects in terms of value and priority.

The role of the JSIP in terms of the City's infrastructure intelligence and decision-making is clear in the context of financial reporting from the Municipal Systems of Chartered Accounts (MSCOA) reforms, which come into full effect in July 2017 and standardizes all municipal accounting as well as reporting practices across South Africa (IMQS, 2017). This reform requires that all metropolitan municipalities have comprehensive spatially targeted and prioritized capital investment frameworks, effectively "giving teeth" to CIF. The nature in which CIP and JSIP unfold together will yield critical insights into how Johannesburg responds to the MSCOA reform.

The co-evolution of the CIP and the JSIP is also fundamental to the City's ability to respond to its infrastructure challenges sustainably. In many ways, the CIP reinvigorates both the planning environment and technical capacity that enables the City to report on sustainability priorities by aligning infrastructure needs with level of function and geographic areas. While there is a history of decision-support within the City, the JSIP appears to emerge under the CIP as part of a shift towards integrating planning, thus establishing the foundations for more sustainable urban management. Applications in neighboring cities Ekurhuleni and Tshwane are examples of how municipalities are investing in decision-making systems to address their urban management challenges. CP^3 initiatives in these cities are also the product of knowledge-sharing platforms and user-group interactions between municipalities, which shows the possibility of using the software collaboratively (Scheepers, 2018).

While an organization's institutional memory does not necessarily reside in a single person, interviews with various stakeholders confirm that an ex-director of the Department of Development Planning (DDP) not only "champions" the early CIMS pilot, but also plays a key role, together with a number of other individuals, in the earlier SDF and GMS processes (Götz, 2017; Scheepers, 2018; Van den Berg, 2018; Viljoen, 2018). The various reflections of former officials show the effect of lost personnel on decision-making processes. Possibly as a result of the 2016 political changeover, which sees an institutional review, the Development Planning Department (DPP) loses the director who drives the CIMS in its early incarnation at city level (CoJ, 2017e; Götz, 2017; Van den Berg, 2018). At the time of writing, the City is yet to fill this position, and the DDP remains without a departmental head.

The longevity of the series of technical experiments and decision support platforms of the City's infrastructure planning efforts are therefore worthy of critical reflection. The reincarnation of CIMs as the JSIP reveals that these sense-making processes, in Weick's framing (1995), are often complex modelling, reporting, prioritizing and analysis efforts by a City attempting to understand as well as manage competing demands. In doing so, the City is not only narrating the multiple stories about Johannesburg's infrastructure, but is also attempting to locate the decision pathways of doing so practically. Reading these processes ethnographically shows how understandings of values are written into or "encoded" (Star, 2002: 7) into the internal structures of the City and that may be peripheral to normative readings of urban sustainability.

5.5 Key insights

This chapter reflects on Johannesburg's infrastructure challenges from the perspective of the municipality and offers two categories of insight.

1. Planning conundrums

With water as the focal point, a first insight derives from revisiting Johannesburg's infrastructure challenges, which indicate that a more sustainable approach to infrastructure planning and management is essential, yet implementation faces some practical difficulties. Building on work by Götz and Schäffler (2015), the difficulties, such as aligning rights agendas or political imperatives with the need for resource efficient infrastructure, within a capital budget in a climate of mounting fiscal constraints, can be interpreted as planning conundrums. This re-reading of infrastructure challenges from the perspective of the City helps understand some of the paradoxes relating to Johannesburg's infrastructure failures and dysfunctionalities (Star, 1999).

A review of Johannesburg's water challenges also raises questions about the prudency of the municipality's current fiscal approach and the growing dependence on loans to fund future capital investment. After a relatively strong cash-flow period following the municipal amalgamation, there are pressures not only to redress service backlogs, but also to outlay new infrastructure and overcome a legacy of deferred maintenance. The need for infrastructure "catch-up" poses a planning and policy dilemma of where the cost or burden of future infrastructure investment lies. The chapter's anecdotes about water services illustrate the importance of understanding this challenge for the City, as well as considering funding alternatives, such as development charges that leverage the revenues from property for infrastructure reinvestment. Alternative infrastructure financing models are critical to future research and strategy looking to ease the City's long-term fiscal situation.

2. Infrastructure histories and the tools of practice

A second layer of insights emerges from the entering the internal structures of the City to understand the foundations for sustainability decision-making. Specifically, the chapter foregrounds the infrastructure planning tools in the City as knowledge about where sustainability values will practically take root. This casts light on the efforts underway as the City grapples with its pressures, and on how a series of planning narratives, experiments and people historically coalesce around infrastructure. Historical perspectives are an indispensable part of these insights, building on the important contributions from scholars studying Johannesburg's immediate post-1994 history.

In particular, the chapter shows that the City has made efforts to both understand and respond to its infrastructure challenges by investing in specific layers of decision support. There is an important history of technical experiments and software tools that underpin this capacity. Apart from some initial analysis by Pieterse (2017), as well as the spatial interests of Todes (2012) and Harrison and colleagues (2014), these decision processes, particularly as they correspond to infrastructure planning, remain largely a nascent enquiry. This chapter's analyses therefore contribute some deeper insights, as scholars await the maturity of unfolding CIP and JSIP processes. In many ways, it is also important to appreciate that while it faces challenges, Johannesburg's CIMS pilot is a precedent for the JSIP and CP^3 software gaining traction nationally.

There is also a notable history of municipal visions that signals a degree of institutional and strategic cognizance around the need for a more sustainable planning context. High-level processes such as the GDS, its earlier GMS incarnation, and the SDF, indicate important long-term shifts. The CoF is significant as a potential transition towards transport-oriented and mixed-use development for the City to address it's sprawling geography of poverty (Pienaar, 2016). While the CIP represents specific attention by the City to align its infrastructure future across its service delivery agents, in many ways, it brings into focus the structures and practices that are necessary for materializing sustainability visions.

The periods of hollowing-out of technical capacity in the City are cause for concern. Tracing these histories shows that difficulties often arise in the process of planning. Van den Berg, for instance, reflects that "[w]hen Aurecon bills for time and the City cancels due to sudden political priorities, a problem becomes more acute because of the link between the CIP and public budgets" (2016). From the City's perspective, consultant outsourcing to Aurecon and others is not only costly for the City, but also sometimes creates knowledge cleavages as the earlier CIMS history shows. $NOUVS^3$ benefits from being the service provider of a vast decision platform such as CP^3. Yet the longevity of the CIMS logic, and its applications elsewhere, show the value of dynamic, multi-variate decision tools in supporting municipal infrastructure planning capacities. The shifting national legislative environment, particularly around MSCOA in 2017, also indicates that these types of decision tools will play an even greater role in the future. In addition to comprehensive and standardized infrastructure reporting, one of the MSCOA outputs is the visibility of the capital investments of other municipalities, strengthening the case for collaborative user-group approaches to capital planning and prioritization. Scheepers (2018) argues that municipalities can therefore benefit from provincial and national project databases on similar platforms in the same planning jurisdiction.[30] The placement of JSIP within BEPPs is an example of this shifting planning context in accordance with the Division of Revenue Act (DORA).

5.6 Conclusions

The chapter concludes that the decision-making tools and processes associated with Johannesburg's infrastructure planning environment present a significant opportunity for critical reflection about urban sustainability value shifts. Tools, such as JSIP, contain insights about how the City is valuing its future, as well as knowledge about infrastructure in real terms. In addition, the CIP unfolds at a significant time in the City's history. After several years of institutional review, the SDF and CIF are coming to fruition and provide critical links between spatial and infrastructure planning.

The co-evolution of SDF and CIF also reflects the potential for urban sustainability as a municipal value. The SDF grounds the City's *2040 Growth and Development Strategy* (GDS) in principles of "liveability, resilience and sustainability", offering Johannesburg an opportunity to address its legacy of sprawl and unequal spatial form. There is an emerging interest from the City's Environment and Infrastructure Services Department (EISD) in green infrastructure as a cross-cutting service delivery strategy (Götz & Maree, 2017). While very much in its preliminary phases at the time of writing, the interest from EISD in green infrastructure is potentially revolutionary, shifting from traditional green space planning, such as parks and tree-planting, to a services-based interpretation of green infrastructure. There are also shifts in the City's 2017/18 IDP review, which identifies outcomes, including "environmentally sustainable practices", the adoption of the Sustainable Development Goals (SDGs) and the sustainable development mandates of Africa Agenda 2063 (CoJ, 2017a: 17).

The change in political leadership is an anomaly in Johannesburg's post-1994 history and a potential change of direction as the institutional reviews illustrate. However, initial observations of the 2017/18 IDPs and the arrival of JSIP show that many previous processes are still on course. Tracking the future trajectory of these unfolding infrastructure processes is an essential part of understanding how the City's history of planning narratives, decision-making and institutional momentum will evolve in relation to shifting values.

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[30] Scheepers further notes that in the forthcoming 2018/19 BEPP documents, Johannesburg, Tshwane and Ekurhuleni all benefit from a provincial and national CP^3 system hosted and maintained by $Novus^3$. These provincial and national projects are spatially reported within the metropolitan integrations zones (spatially targeted areas) based on the collaborative user-group approach (2018).

In much the same way as the CIMS experiment is historically important, setting a precedent for integrated infrastructure planning in South Africa, future research needs to deepen its understanding of the work of infrastructure practitioners in grappling with their cities. An ethnomethodological reading of infrastructure is a useful starting point. Culturally, however, understanding the extent to which values manifest in infrastructure practice needs to dovetail with recasting the assumptions about the conditions that satisfy sustainability agendas.

PART 3: CONCLUSIONS

Chapter 6. Closing thoughts and research implications

I began this research at the interface between urban sustainability thinking and practice, where I identified a value shift occurring in relation to, but also challenged by, urban infrastructure. I observed that urban services, such as water supply and sanitation, goals such as natural resource conservation and climate mitigation are increasingly identifiable in many infrastructure contexts. My hypothesis was that these multifunctional goals represent a value shift taking place at some level in society, but there are conundrums that complicate practice.

I initially investigated the hypothesis at an epistemological level by unpacking the scholarly discourses taking charge of urban sustainability, which is a fusion of overlapping, yet divergent interests. Identifying the nature of this synthesis as well as its cleavages is an intervention in existing literature and this awakened me to the underlying base of practical work that supports sustainability. A first, familiar practice comes from the policy–science nexus, but this is one that required critical reflection in terms of the underlying epistemic communities (Haas, 1992: 3) taking charge of urban sustainability discourse. There is an equally, if not more, important practice of infrastructure pilot projects by cities seeking sustainable approaches to providing most of the basic urban functions. As Rouse reflects, while physical infrastructure is the means for change, the objective comes from asking "what service where" (2014: 21). The dissertation presents a simple heuristic through which to examine the stories of urban functions as told by various cities' infrastructure.

Occupying a particular place in physical design disciplines, pilot projects are not only demonstrative examples about sustainability, but they also overturn existing conceptions or theories about infrastructure. Yet the causal nature relationship between sustainability and infrastructure is often complex, as many practitioners are also theorists, while the burgeoning body of sustainability theory is sometimes difficult to decipher in practice. To address this opacity, the dissertation placed urban infrastructure in a historical context, assessing the extent to which ideas about sustainability manifest and contribute to conceptual evolutions. Building on the foundational work by Tarr (1979), Melosi (1993) and other historians and urban geographers, the research developed a trajectory by considering the negative role of urban water infrastructure in history. It is partly this critique within the ecological turn that explains the widespread interest in sustainable urban water infrastructure. As the trajectory shows, however, this critique also connects to the traditions of urban landscape architecture and environmental planning experimenting with designs that provide multiple benefits. Designers, planners and other physical environment practitioners have played a critical role in overturning, refining and developing single-purpose ideas about urban infrastructure. A key area for future research is to use this practical work as a channel for learning about how urban sustainability manifests.

Within the ecological turn in urban planning, the burgeoning discourse on green infrastructure is one of the most vocal articulations of multifunctional concepts. Many practitioners view green infrastructure as a reiteration of earlier work, such as McHarg's pilot at *The Woodlands* or the various urban drainage experiments already underway in the latter half of the twentieth century. An understanding of these histories is a vital part of gaining clarity on what multifunctional infrastructure means. Under the broader influence of ecology, multifunctional concepts often imply something physical and emerge as outcomes of applying ecological principles to landscapes. There is also a strong interest in multifunctional infrastructure from economic perspectives, which increasingly align with ecological perspectives in assessing the different values of physical landscapes. Overall, however, these cultural initiatives show that humans are, in some way, attempting to value their interactions with the physical environment.

While many questions remain about how humans perceive, engage, design for and evaluate the physical environment, the articulation of multifunctional ideas reveals the nature of collective assignments of meaning. Engaging history is an indispensable part of learning how humans collectively, yet divergently, redefine the physical environment. This in turn shows that in addition to something physical, multifunctional infrastructure is also an inherently constructed notion. Branches of axiology and constructivism are therefore useful locations for future research approaching multifunctional infrastructure from a cultural perspective.

In addition to cultural geography and social studies of technology, Susan Leigh Star's *The Ethnography of Infrastructure* (1999) provides a particular opportunity. Star calls for "unfreezing" infrastructure and prompts a provocative enquiry into the underlying narratives, work and paradoxes behind mundane objects. However, her trio of tricks (Star, 1999: 384) requires interventions for establishing the grounds of what these tricks might imply in practice, and these find a useful ally in Garfinkel's ethnomethodology (1967). While there are numerous possible augmentations and refinements of Star's ideas, a particular opportunity from Garfinkel's work lies in the methods that practitioners use for assessing multifunctional values. These methods naturally fit into Star's second trick, "surfacing invisible work" (1999: 385), and not only provide evidence of how future visions of infrastructure are valued and assessed by their users, but also flag the hidden layers of decision-making happening behind the proverbial end-of-the-pipe.

The challenge with grasping how future visions of infrastructure materialize is that there are multiple constructions, legitimizations and legacies – politically, sociotechnically, legally and geographically (Graham, 2000: 198). This is indeed the case in Johannesburg, where a series of infrastructure challenges and competing discourses coincide. The case study revisits these to understand how a municipality emerging from a heady political–economic transition needs to position itself to respond appropriately to its infrastructure challenges. In Johannesburg, the conundrums of sustainability present strikingly in water infrastructure, yet it is common to analyze these from precepts about what more sustainable visions might imply. Embarking on the case study instead from within the City reveals the methods of infrastructure practice that have been largely peripheral to existing scholarship. This might reflect a lack of interest on the part of critical scholars in the work of multivariate analysis and asset management, or that the evidence base evolving in the municipality around infrastructure decision support is only at the cusp of its full potential. Here again, historical analysis has been an invaluable contribution to updating some of the foundational analysis of Johannesburg's post-1994 transition. The unfolding Consolidated Infrastructure Plan (CIP) and its supporting decision software, the Johannesburg Strategic Instructure Program (JSIP), remain the imperative enquiry into whether, and how, the municipality anchors shifting sustainability values in the necessary structures for decision support.

This dissertation shows the complexity that is infrastructure planning in Johannesburg and attempts to shed light on the potential of using the underlying decision processes, such as software systems, multivariate models or asset management plans, as knowledge about shifting values. As the relevant infrastructure planning processes unfold, this dissertation's efforts of surfacing invisible work (Star1999: 985) can be applied to how the municipality is repositioning itself in its various sustainability engagements. While these are often intermittent, there are indications that green infrastructure is gaining purchase, together with existing engagements with green economy and sustainable resource initiatives. The 2016 political shift also signals a potential interval for how future city visions might proceed. However, one of the greatest possibilities for future research lies within the municipality itself, in its history of efforts at understanding how its city, Johannesburg, is growing, evolving and negotiating its divergent pressures.

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Appendix A

Interview scripts

Proposed Interview Script

Verbal / Email Script for Recruitment

Dear Sir or Madam,

My name is Alexis Schäffler and I am a Ph.D. student at the University of California, Berkeley, in the Department of Landscape Architecture and Environmental Planning (LAEP). My dissertation research is about how the idea of urban sustainability affects the practice of infrastructure.

I am seeking your experience in [context] to understand what tools infrastructure practitioners have available for engaging sustainability ideas. I would like your participation in this interview to understand this question.

If you are willing to participate, I will conduct an interview with you. Your participation is voluntary and you can stop at any time. If you wish to, you can remain anonymous.

If you agree to the interview, we can schedule an appointment a time and location that is suitable for you.

Are you interested in participating? Do you have any questions?

[Email] If you have any questions, please feel free to contact me by email at alexis.schaffler@berkeley.edu

Best,

Alexis Schäffler

Appendix B

Interview method

1. Semi-structured interviews

Purpose: I use semi-structured for my case study research (Chapter 6) to clarify the historical facts of the municipal amalgamation within the City of Johannesburg (CoJ) in early 2000s. This process of amalgamation also gives rise to a series of new infrastructure planning tools that I seek to elucidate.

Selection of interviewees: Specifically, I interview current and ex-public officials interviews to enquire about the history of the CoJ's infrastructure strategies that have roots in the municipal amalgamation. For instance, during interviews with previous public officials, I ask the following questions:

Question 1: What are the roots of the CIP?

Ex-official: The CIP has a prehistory in several earlier planning processes and experiments by the City to manage its infrastructure challenges. During the 2011-2015 term of mayor Parks Tau, the City undertakes a review of Johannesburg's growth management and development direction. A strategic process, the Growth and Development Strategy (GDS), provides the long-term development vision for Johannesburg and replaces the earlier Joburg 2030 plan by linking infrastructure implementation to spatial planning. At the same time, the City introduces the Spatial Development Framework (SDF) that defines its spatial vision and means of implementation. The GDS evolves into the 2008 Growth Management Strategy (GMS). As these two processes evolve, the City experiments with a system for prioritizing infrastructure investment. The initial system, essentially a Microsoft Excel spreadsheet, determines infrastructure need in terms of priority and spatial factors. The spreadsheet becomes the Capital Investment Management System (CIMS).
This example question shows the facts I seek to clarify about evolution of infrastructure planning in relation to the wider institutional processes.

Question 2: How does the Capital Investment Management System (CIMS) evolve into Consolidated Infrastructure Plan (CIP)?

Ex-official: The CIMS was actually a precursor to the Growth Management Strategy (GMS), that follows after the municipal amalgamation. The context at the time is the City facing major development pressures and a history of infrastructure backlogs due to apartheid. In addition to the growth management philosophy, CIMS was essentially and excel spreadsheet listing all infrastructure investment requirements, priorities and implementation. The CIP is a more recent attempt by the City to improve on CIMS, specifically in terms of spatial prioritization.

In terms of this example question, there is publicly available information on the CIMS. For example:
The purpose of the CIMS model is to ensure alignment of the capital investment programs with the Mayoral priorities, the development paradigm and sector programs of the GDS and the development direction of the SDF. Further, it provides an understanding of the development implications of certain investment decisions.
(CoJ 2006: 128)

While is public information available in municipal documents, I interview public officials and planners in order to clarify the function and nature of public planning tools, such as CIMS and the CIP. Thus, I ask a public official the following:

Question 3: In terms of the City's previous tool the Capital Investment Management System (CIMS), what tools does the CIP use for infrastructure prioritization?

Planner: Following the Spatial Development Framework (SDF) and the momentum of CIP process within EISD, the City to replaces the CIMS with the Johannesburg Strategic Infrastructure Platform (JSIP) in 2015/16. The JSIP is also a capital planning and management platform but is a "finer-grain" tool for cataloguing and prioritizing infrastructure projects.

Question 4: What data do you use to inform the CIP and ultimately the JSIP?
Planner: The socio-economic models from an earlier process, the Growth Management Strategy (GMS) inform baseline infrastructure projections.

These questions were part of a series of semi-structured interview during which I was trying to clarify the data and tools that form the CIP as a public planning process. Specifically, I was attempting to clarify the difference between the CIP and JSIP tools.

<u>Analysis:</u> To summarize, I used semi-structured interviews in my case study on Johannesburg to clarify facts about municipal infrastructure planning. I interviewed public officials to clarify historical facts and the purpose of more recent public planning

tools. During my participant observation research, I observed the key ideas and narratives that emerge in urban sustainability research forums.

2. Participant observation

In terms of my participant observation, a range of participants are relevant to urban infrastructure planning. These include government employees, planning advisors and what I define as "academic planners" in a group of planning practitioners. Due to my previous career as an academic-planning advisor, much of the participant observation in the research draws on my own historical experience and observation.

In terms of the more recent research, I was asked to attend various research meetings with the Gauteng City-Region Observatory (GCRO), a research partnership between universities, local and provincial government in Gauteng, South Africa. These occurred between September 2016 and August 2017:

GCRO Green Infrastructure Research discussions
GCRO Governance of Flows Research discussions
GCRO Dimensions of a Green Economy discussions

In these research discussions, I explained upfront to the participants that I was engaged in research tracing the shift in urban sustainability values over time. I observed the urban sustainability narratives and how these emerged in relation to themes on urban infrastructure. For instance, I observed that while the GCRO plays a key role but in advancing theories about urban sustainability, strategic momentum hinges upon the nature of political commitments, fiscal incentives and bureaucratic processes

Appendix C

Interview profiles

a) Graeme Götz, research director, and Gillian Maree, senior researcher at the Gauteng City-Region Observatory (GCRO).

b) Tiaan Ehlers.
Ex-official at the Environmental Services and Infrastructure Department (EISD) CoJ

c) Peter Magni.
Ex-official at Department of Infrastructure Management, City Transformation and Development Planning, CoJ.

d) Peter Ahmed.
Ex-official Central Strategy Unit, CoJ.

e) Kamini Pillay
Assistant Director at Environmental Services and Infrastructure Department (EISD)

f) James Scheepers.
Engineer at NOVUS3

g) Bernard Viljoen
Engineer at NOVUS3

h) Johan van den Berg
Engineer at Aurecon